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MCR-73-2

ABLATIVE AND METALLIC HEAT SHIELDS

FOR AEROBRAKING REENTRY

TASK B-2 REPORT

January, 1973

Contract Number NAS8-27161

(NASA-CR-185940) ABLATIVE AND METALLIC HEAT SHIELDS FOR AEROBRAKING REENTRY: TASK B-2 REPORT (Martin Marietta Aerospace) 59 p

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Approved by:

Eric L. Strauss

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FOREWORD

This report is submitted in compliance with Phase II, Task 5 (Reports) of Exhibit "A", Scope of Work, dated 06-29-72 for Contract NAS8-27161.

Phase II of the Contract consists of five Tasks:

Task 1: Test Environment and Model Definition;

Task 2: Model Design and Fabrication;

Task 3: Ablator Test and Evaluation;

Task 4: Conference Requirement;

Task 5: Reports;

This report documents the studies performed under Task 2: Model Design and Fabrication.

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I. INTRODUCTION

The objectives of this study were to establish the feasibility of utilizing ablative or metallic heat shields for aerobraking reentry and to ascertain realistic ablative heat shield weights and design criteria for both ablative and metallic heat shields.

The ablative and metallic heat shields were for application to a 14 ft-diameter cylindrical body entry configuration with a 2:1 elliptical dome. Both a low drag and a high drag configuration were studied. The aerobraking trajectory pertained to the transfer of the vehicle from a geosynchronous orbit to the orbit of the Space Shuttle. Aerobraking trajectories involving two perigee passes and 30 perigee passes were investigated.

In the performance of Task 2, "Model Design and Fabrication", the following was accomplished:

1. Flat-faced, 2-1/2-inch and 8-inch diameter ablation test models were designed. The ablators were supported by a honeycomb reinforcement and were bonded directly to an aluminum substrate. Thermocouple instrumentation for the ablator models was defined.

2. Five-inch diameter metallic plasma arc test models were designed and detail drawings were prepared. Thermocouple instrumentation was defined for columbium and Haynes-188 models.

3. Twelve ablator test models were fabricated and instrumented.

4. Six Haynes-188 models were fabricated from sheet stock supplied by MSFC and instrumented with chromel-alumel thermocouples. Six columbium models were fabricated by MSFC. They were inspected by Martin Marietta, coated with R512-E and instrumented with platinum-rhodium thermocouples. A model holder for the metallic heat shield specimens was designed.

II. ABLATOR MODEL DESIGN AND FABRICATION

Ablator models were designed as flat-faced cylinders for splash testing. For two pass entry simulation, a model diameter of 2-1/2 inch was selected as consistent with the three-inch diameter plasma stream. Thirty pass entry simulation was to be conducted in a ten-inch diameter stream and an 8-inch model diameter was therefore chosen. All ablators were supported by a glass-phenolic honeycomb core. The honeycomb was a

Martin Marietta-developed two-directional bending core with a nominal density of 2.3 lb/ft^3. Honeycomb-reinforced ablator slabs were fabricated by using a vibration/pressure technique to press the honeycomb into the uncured ablator. The ablators were then bagged and vacuum cured at a peak temperature of 300^{o}F. The cylindrical ablator specimens were rough cut from the slabs and machined to final diameter and thickness. 0.156 in. aluminum, representative of the equivalent thickness of the aluminum backup structure at the stagnation point, was bonded to the ablator backface with a Martin Marietta silicone adhesive.

The model configuration for two pass testing is shown in Figure 1. Ablators selected for low drag entry simulation were ESA 5500 (two models) and ESA 3560. For high drag entry simulation, ESA 3560 (two models) and SLA-561 were selected. Ablator thicknesses listed in Table 1 are those calculated for a 300^{o}F backface (aluminum) temperature at the stagnation point. However, the as-fabricated height of the ESA 5500 ablator was 2.03 rather than 2.08 inch. Specimens were instrumented with Platinum-Pt-13% Rh, Chromel-Alumel, and Iron-Constantan thermocouples as defined in Table 1. Pt vs Pt-13% Rh thermocouples were connected to copper extension wire immediately aft of the aluminum stud. The periphery of the models was wrapped with fiberglass tape to insulate the aluminum backface and to prevent ablator loss from the open honeycomb cells. The ablator models are shown in Figure 2. A 3X enlarged view of the ablator surfaces are shown in Figures 3 through 8.

The model configuration for thirty pass testing is shown in Figure 9. Ablators selected for entry simulation (high drag configuration) were ESA 3560 (four models) and SLA-561 (two models). Ablator thicknesses listed in Table 2 are approximately 5 percent greater than thicknesses calculated for a 300^{o}F aluminum temperature. The extra ablator was added as a safety factor. Specimens were instrumented with Chromel-Alumel and Iron-Constantan thermocouples as defined in Table 2. The periphery of the models was wrapped with fiberglass tape. The ablator models are shown in Figures 10 through 15.

III. METALLIC MODEL DESIGN

The metallic heat shield models were designed as five-inch diameter flat-faced specimens for splash testing. To protect and stiffen the vulnerable edges, the periphery was bent 90 degrees with a 1/4-inch radius. Three legs, spaced 120^{o} apart, were welded to edge tabs for model attachment. The Haynes-188 model configuration is shown in Figure 16. The cap is made from 29 mil sheet and the legs from 15 mil sheet. The specimen is preoxidized to obtain a uniform, high emissivity surface. The FS-85 columbium alloy model is shown in Figure 17. The cap is made from 25 mil sheet and the legs from 20 mil sheet. The columbium models were coated with R-512E silicide (HiTemCo - De Wiant Corp., Hicksville, New York) for oxidation protection.

Thermocouple instrumentation is defined in Figure 18. Eight thermocouples are located to measure stagnation point temperature as well as the radial and circumferential temperature distribution and the temperature of the leg. Haynes-188 models are instrumented with Chromel-Alumel thermocouples which are attached to the inner surface by tack welding. The columbium models require Platinum vs Platinum-13% Rhodium thermocouples. The thermocouples are tack welded to 5 mil rhodium foil which in turn is attached to the coated inner surface with a ceramic cement.

Test installation for the metallic plasma arc models is shown in Figure 19. The models are bolted to a reinforced plastic base plate with 1/4-inch stainless steel bolts, nuts and washers. The space between model cap and base plate is filled with fibrous insulation.

IV. METALLIC HEAT SHIELD FABRICATION

Six Haynes-188 plasma arc models were fabricated in accordance with Drawing No. 1630-72-026 (Figure 16), except that the legs were spot welded rather than seam welded to the tabs. Superficial hardness tests were conducted on the "as received" HS 188 material and an average Rockwell reading of A-56 to A-59 was recorded. This condition is considered adequate for "deep draw" forming of Haynes-188. Fabrication procedures are summarized below.

A deep draw forming die was fabricated from 6061-T651 aluminum alloy (Figure 20). The finish die working surfaces were "hard coat" anodized to prevent damage to the die and the model details during the "deep draw" forming operation (Figure 21). Model cap material (0.0295-inch thick HS 188) was sheared into 8-inch x 8-inch squares for forming. The squares were then clamped in the forming die. The punch was inserted on top of the HS 188 material and forced down through the form die using a 100 ton Dake hydraulic press. This essentially draws the material around the punch nose and down through the die body (Figure 22). The upper and lower sections of the forming die maintain a high clamping force against the HS 188 material, allowing the material to draw-in during the forming operation but preventing or eliminating peripheral buckling in the HS 188 material (Figure 23). MS-122 fluorocarbon release agent/dry lubricant was used during forming to prevent galling.

The formed caps (Figure 24) were vacuum furnace solution annealed at 2150°F for 30 minutes to relieve the cold worked condition resulting from the forming operation. Following the solution anneal, the caps were laid out for leg locations and cap depth. Excess material was trimmed by sawing and the final finish of the caps was obtained by grinding and hand filing.

The leg details were laid out and sheared to size. The 90^{o} angle was formed using a conventional air brake forming process. Mounting holes were drilled in the leg details using high speed drills with special sheet metal points. All HS 188 details were chemically cleaned in preparation for welding.

A special positioning fixture (Figure 25) was fabricated for locating the legs in the proper plane and radial position for joining to the cap. Details were assembled to the fixture and resistance spot welded using the Sciaky 100 KVA spot welding machine. Two welds were made on each leg to attach it to the cap. Preproduction weld samples and one post-production weld sample were made. The following are the results of the tensile test specimens (see Figure 26):

Specimen Number	Number of Welds	Load (lbs)	Location of Failure
1	1	600	Heat affected zone
2	1	600	Heat affected zone
3	2	860	Parent material
4	2	970	Heat affected zone in .015"
5	3	1030	Heat affected zone in .015"
6	3	1130	Heat affected zone in .015"
7	2	820	Parent .015" material
8	2	900	Parent .015" material
9	2	770	Parent .015" material
10	2	900	Parent .015" material
11	2	800	Parent .015" material
12	2	850	Weld Nugget Failure

Sample No. 12 was the post-production resistance weld sample. All samples were made from material thickness combinations representative of the production article.

Following the welding operation the entire inner and outer surfaces of the model were vapor honed using the Pangborn blast cleaning system. Assemblies were then water rinsed, vapor degreased, submerged in Oakite 90 for 10 minutes, demineralized, water rinsed, and baked dry at $200^{o}F$. The cleaned models are shown in Figure 27.

The final manufacturing operation was to preoxide coat the models. An atmosphere furnace capable of reaching 1900°F was employed for this purpose. The furnace was elevated to 1000°F (no load). The models were loaded in the furnace at 1000°F. Temperature was then increased to 1900°F and held for 30 minutes. The models were removed from the furnace and rapid air-cooled to room temperature. Models after preoxidation are shown in Figures 28, 29 and 30.

The six models were instrumented with Chromel-Alumel thermocouples in accordance with Drawing No. 1630-72-020 (Figure 18). A view of an instrumented model is shown in Figure 31.

FS 85 columbium alloy models were furnished as GFP articles by the George C. Marshall Space Flight Center. The specimens conformed to Drawing 1630-72-025 (Figure 17) except that the legs were butt welded to the tabs and the cap was slightly dome shaped. The as-received models were weighed and measured upon receipt and inspected visually and dimensionally. The visual inspection is documented in Table 3 and in Figures 34 through 42. Edges were suitably rounded for coating. The major anomalies found were a blueish discoloration at the tab-to-leg welds which appears to be the heat affected area, tool marks on the tabs and an indentation on the cap of Model No. 3. Results of the dimensional inspection are summarized in Table 4. The cap out-of-flat condition varies from .014 to .045 inch from the cap center to the edge.

TABLE 1 - Model Specification - Two Pass Heating

Model No.	Material	Height	Thermocouple Location (Distance from Front Face - in.)
1, 2	ESA-5500	2.08*	1 .100 (Platinum-Pt-13% Rh) 2 .300 (Platinum-Pt-13% Rh) 3 .600 (Chromel-Alumel) 4 1.200 (Chromel-Alumel) 5 Aluminum Backface (Iron-Constantan) 6 Thermocouple-Lead Wire Junction (Chromel-Alumel)
3, 4	ESA-3560	1.36	1 .100 (Platinum-Pt-13% Rh) 2 .300 (Platinum-Pt-13% Rh) 3 .500 (Chromel-Alumel) 4 .800 (Chromel-Alumel) 5 Aluminum Backface (Iron-Constantan) 6 Thermocouple-Lead Wire Junction (Chromel-Alumel)
5	ESA-3560	1.43	1 Aluminum Backface (Iron-Constantan) 2 Inner Surface - Plastic Base (Iron-Constantan)
6	SLA-561	1.68	1 Aluminum Backface (Iron-Constantan) 2 Inner Surface - Plastic Base (Iron-Constantan)

*As-fabricated height is 2.03 inch.

TABLE 2 - 8 in. Model Specification

Model No.	Material	Height	Thermocouple Location (Distance from Front Face - in.)
1 2	ESA-3560 (H.C.) 30 Pass Run	2.25	1 .100 (Chromel-Alumel) 2 .300 (Chromel-Alumel) 3 .600 (Chromel-Alumel) 4 1.200 (Chromel-Alumel) 5 Aluminum Backface (Iron-Constantan)
3 4	ESA-3560 (H.C.) 15 Pass Run	2.25	Same as 1 and 2
5 6	SLA-561 (H.C.)	2.00	1 Aluminum Backface (Iron-Constantan) 2 Inner Surface - Plastic Base (Iron-Constantan)

NOTE: Model No. 5 - 30 pass run; Model No. 6 - 15 pass run.

Table 3 - FS 85 Columbium Model Inspection Before Coating

Model No.	Weight (g)	Metal Thickness (in.)		Visual Inspection		
		Cap	Leg	Cap	Tabs and Legs	Discoloration
1	115.1	.0270	.021	Three small gauges on outer surfaces near periphery (Fig. 34). Scratches on inner surface (Fig. 35).	Tool marks on inner and outer tab surface.	Slight discoloration on tab outer surface. Blue discoloration on inside of tabs and upper parts of legs (Fig. 36).
2	112.3	.0260	.0215	Irregular scratches on outer surface. Small marks on internal peripheral radius.	Tool marks on inner and outer tab surface.	Blue discoloration on outer tab surface, extending to cap radius and to upper part of leg (Fig. 37).
3	115.0	.0270	.021	Indentations on both sides, 1-3/4 inch from center near leg (Fig. 38).	Tool marks on inner and outer tab surface.	Blue discoloration on inner surface of cap radius, tabs and legs (Fig. 39), and on outer surface of tabs and legs.
4	112.8	.0262	.0215	Buff marks on external peripheral radius. Irregular scratches on inner surface.	Tool marks on inner and outer tab surface. Variable tab weld penetration and gaps at both ends of weld (Fig. 40).	Slight discoloration on outer tab surface. Discoloration on inner tab surface above and below welds.
5	112.5	.0260	.0215	Nicks near internal peripheral radius (Fig. 41).	Tool marks on inner and outer tab surface.	Faint brown discoloration on outer tab surface at corners. Blue discoloration on inner tab surface above and below welds.

Table 3 (Continued)

Model No.	Weight (g)	Metal Thickness (in.)		Visual Inspection		
		Cap	Leg	Cap	Tabs and Legs	Discoloration
6	112.3	.0260	.0215	Faint scratches on outer surface. Scratches on internal peripheral radius (Fig. 42).	Tool marks on inner and outer tab surface. Contamination on bottom of leg at corner.	Blue discoloration on upper portion of tab and cap radius - outer surface. Blue and brown discoloration on inner tab surface above and below weld.

MATERIALS TEST REPORT

QUALITY CONTROL LABORATORIES

LOT NO. ____________

PAGE NO. 1 of 1

DATE 12/21/72

CUSTOMER 0625-203159-09500-02000

P. O. NUMBER ____________

FROM E. Pracht X2130

SPEC. NUMBER ____________

DESCRIPTION 6 Columbium Plasma Arc Test Specimens
Dimensional Inspection prior to Coating

ACTUAL DIMENSIONS AS TAKEN FROM PARTS

B/P Dimensions	Plasma Arc Test Specimens					
	1	2	3	4	5	6
5.00 dia.	4.950	4.950	4.950	4.960	4.965	4.965
	5.00	4.990	4.990	5.005	4.995	4.990
.75	.82	.735	.725	.725	.720	.725
		.755	.750	.745	.745	.750
.25	.23	.235	.25	.225	.23	.24
.75	.735	.745	.735	.745	.73	.74
2.00	2.050	1.990	2.070	2.070	2.065	1.980
.50	.60	.65	.60	.70	.70	.70
Out of flat condition (from center to two opposite edges) Varies from .014" to .045" from center to edge. Specimens #3, 4 and 6 not measured.	.045	.020			.040	
	.014	.020			.035	

Dimensional Tolerances:

.xx ±.03

.xxx ±.010

Earl Pracht
Quality Representative

Table 4 - Dimensional Inspection of FS 85 Columbium Models

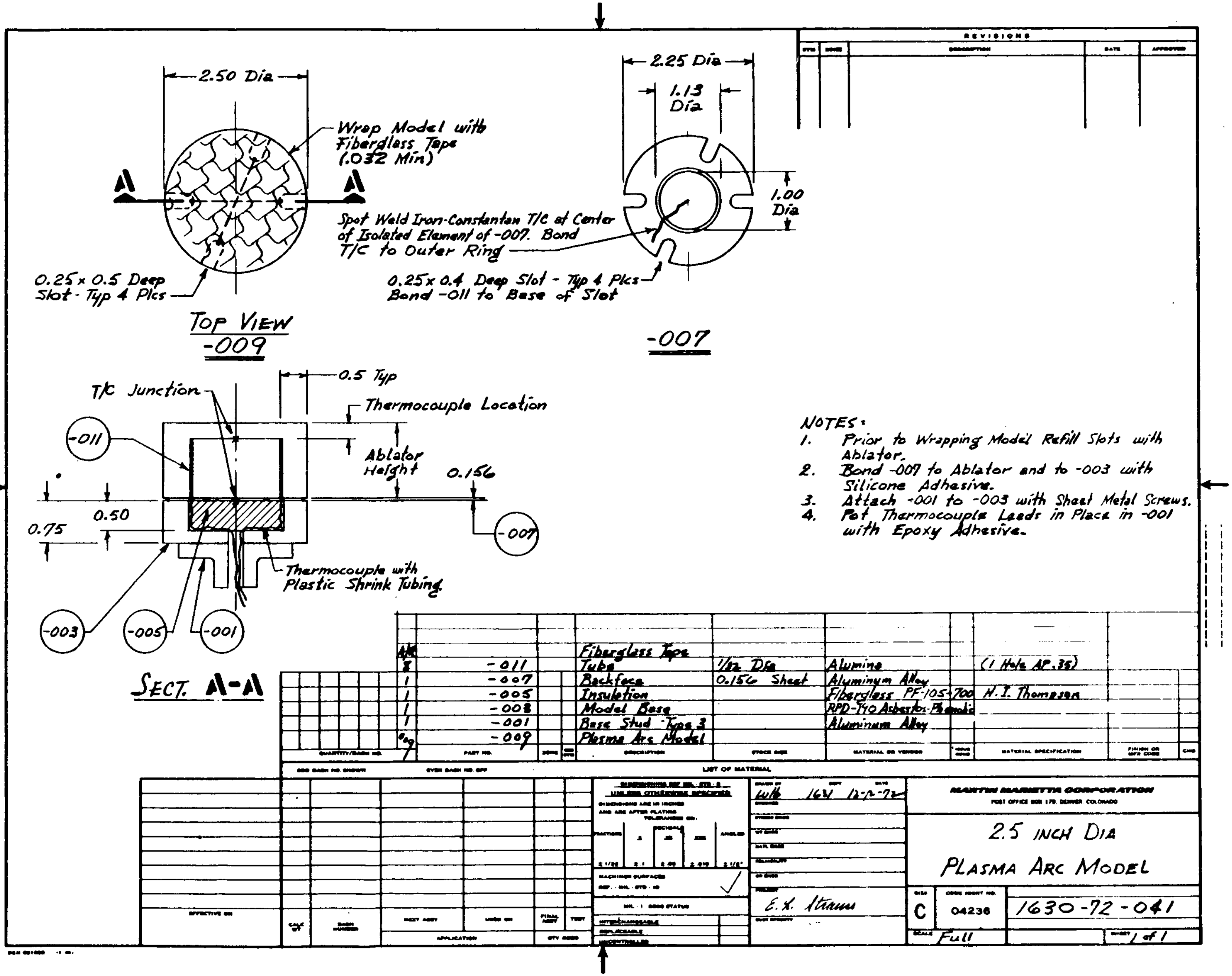
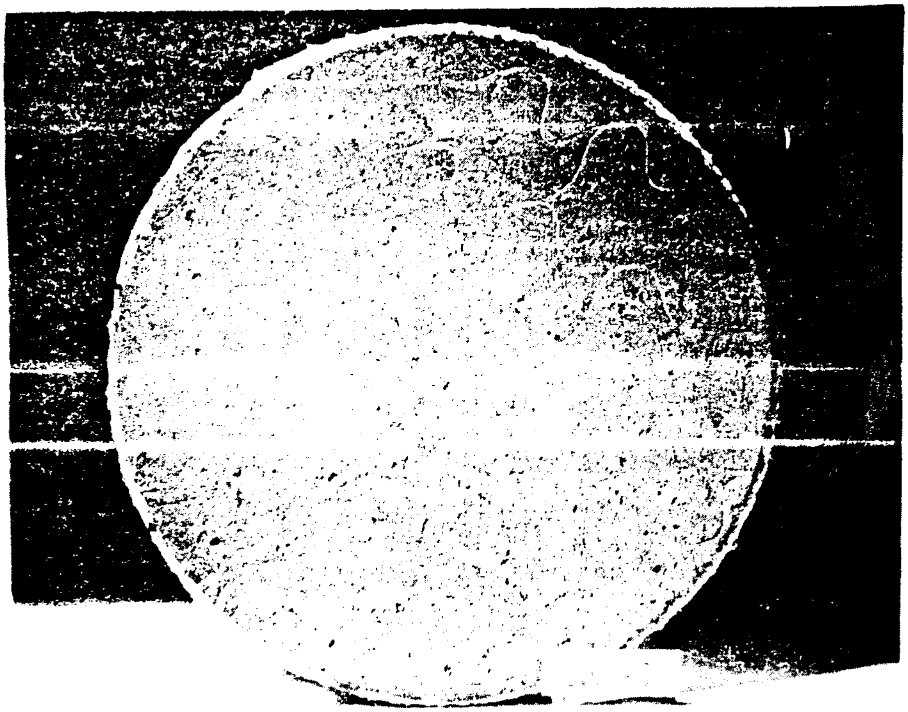
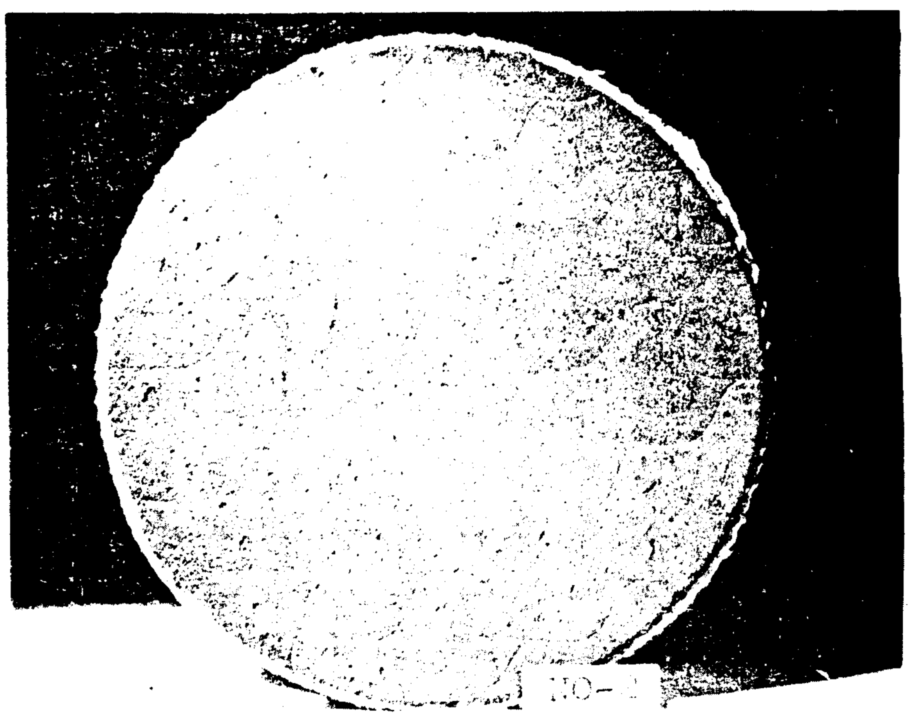


Figure 1 - 2.5-Inch Diameter Plasma Arc Model

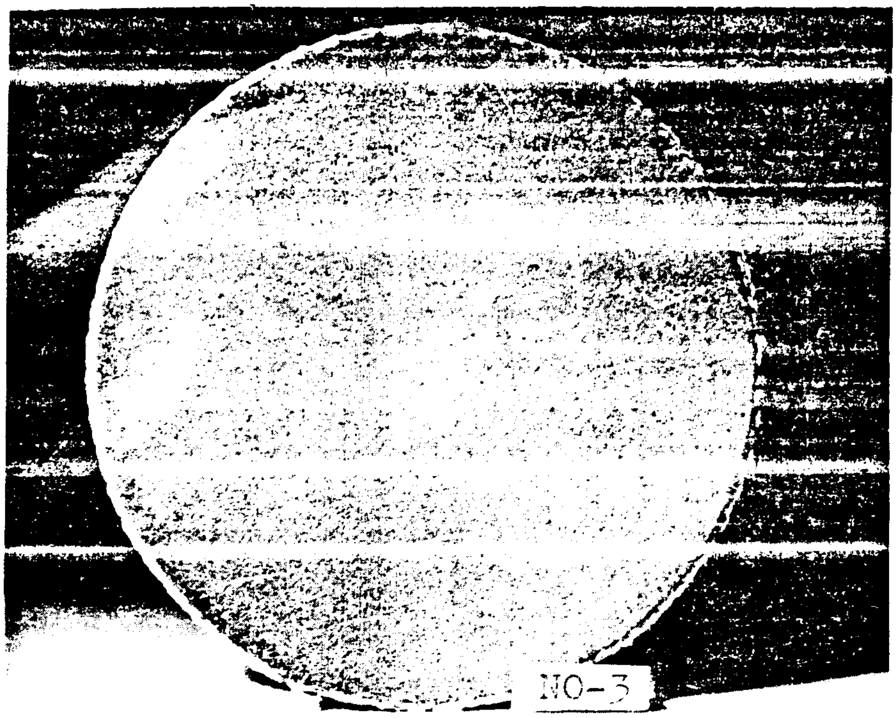


ESA 5500

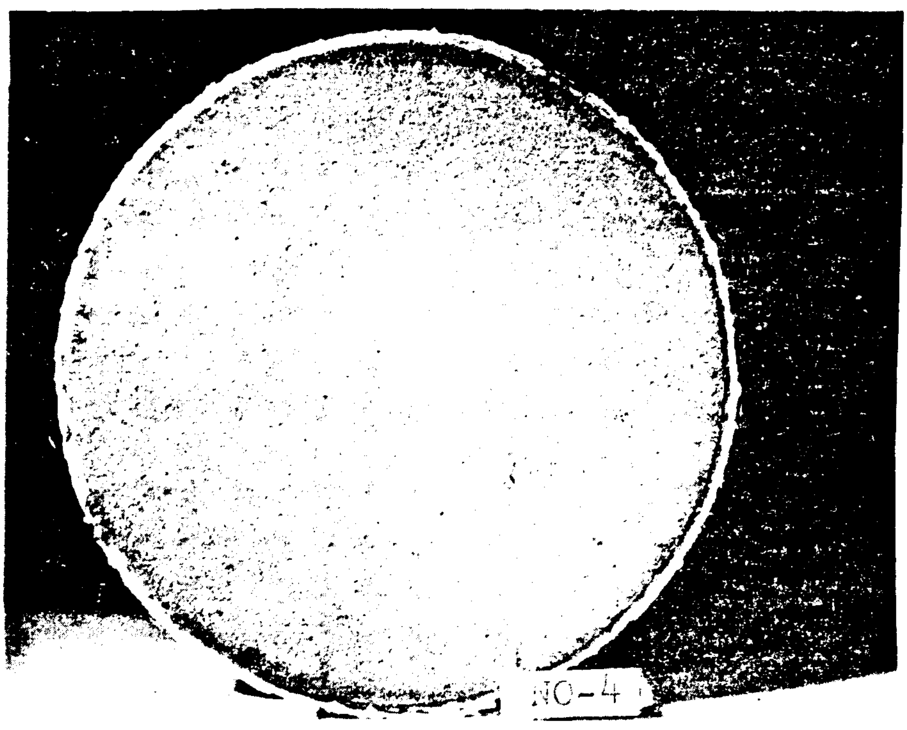


ESA 5500

Figure 2 - Outer Surface of 2.5-Inch Diameter Ablator Models

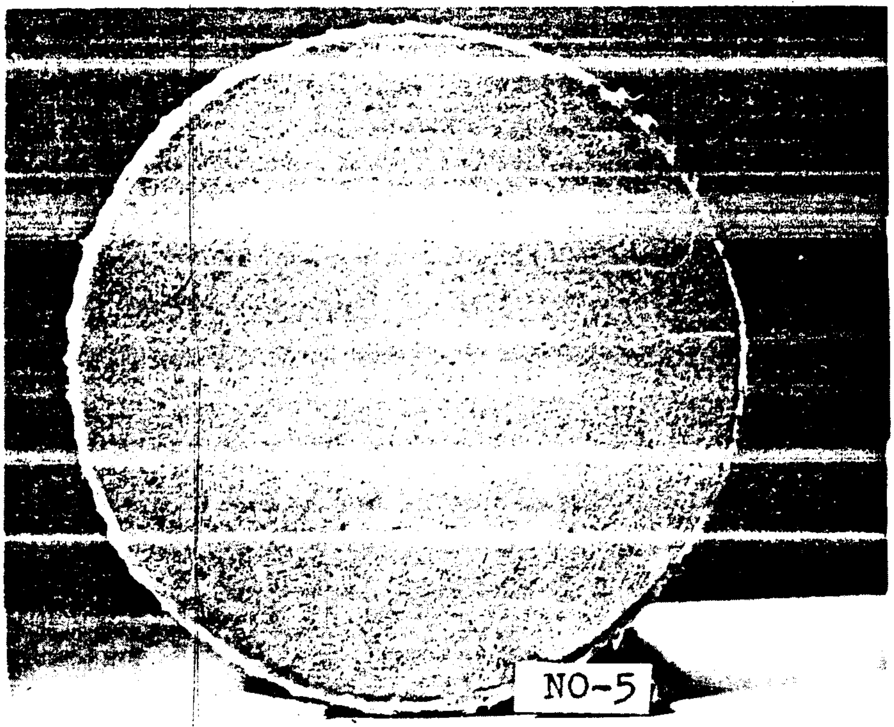


ESA 3560



ESA 3560

Figure 2 - Continued



ESA 3560

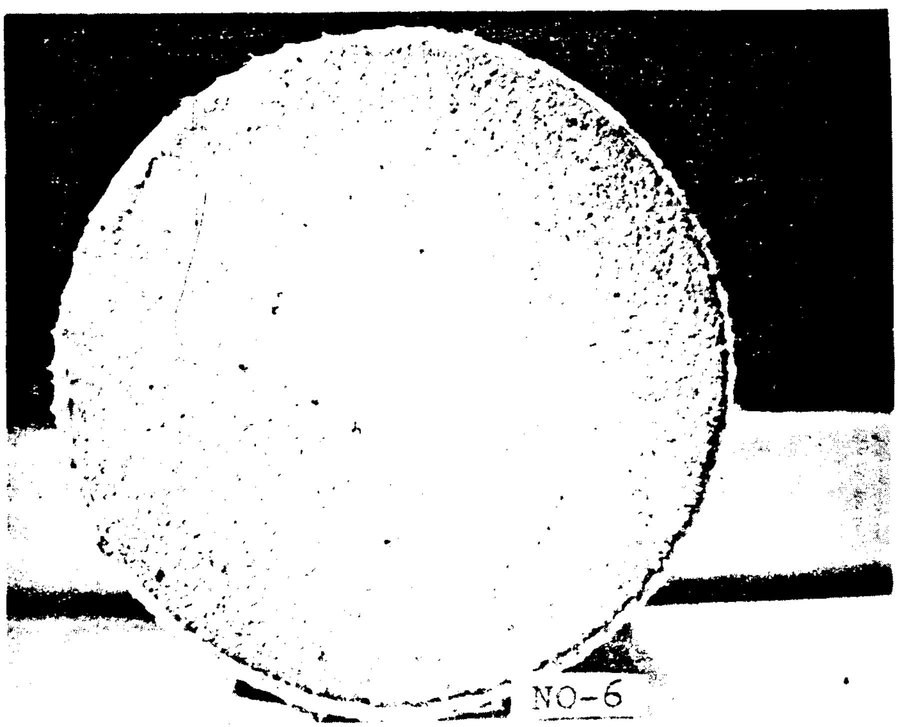


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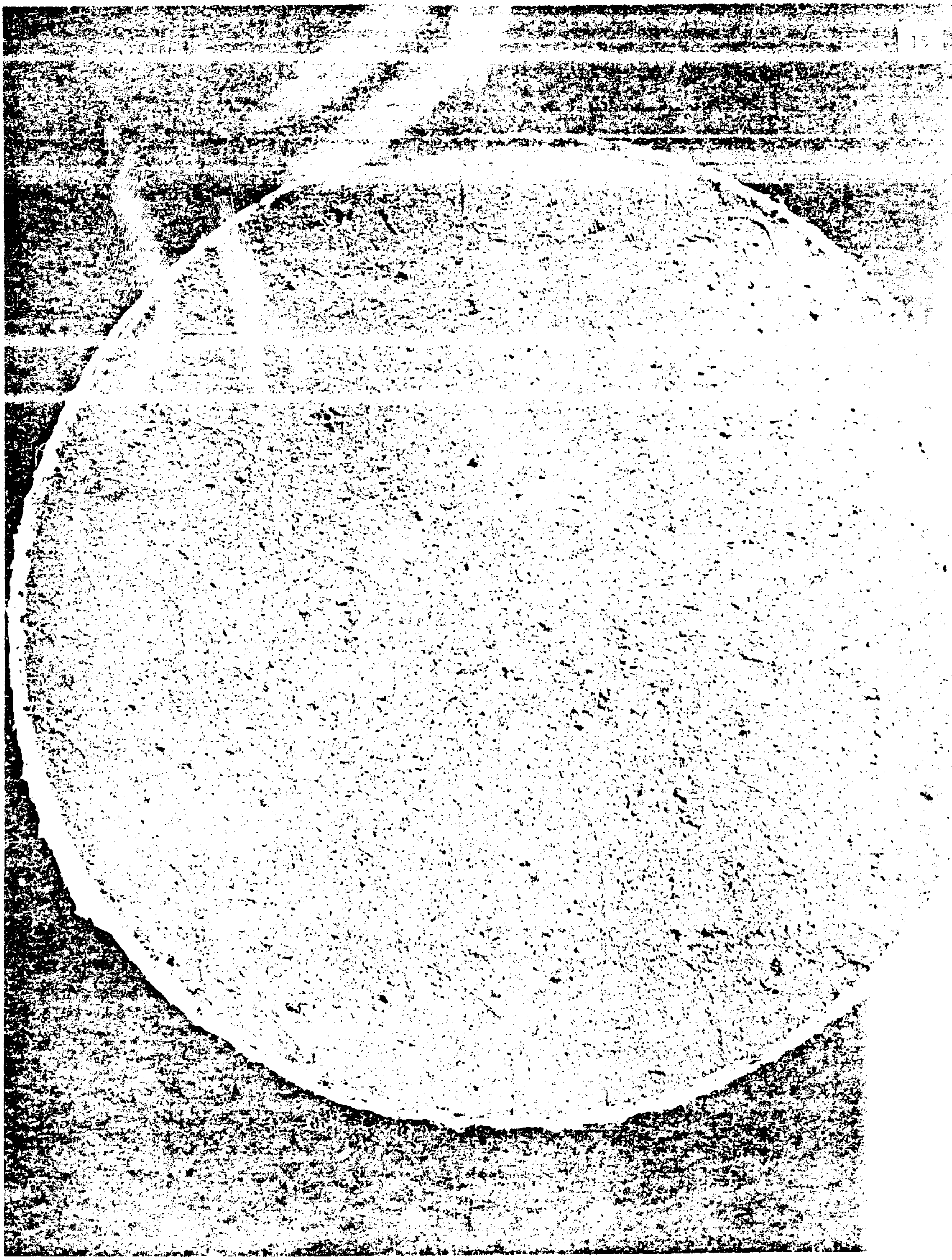
Figure [illegible]. - Concluded



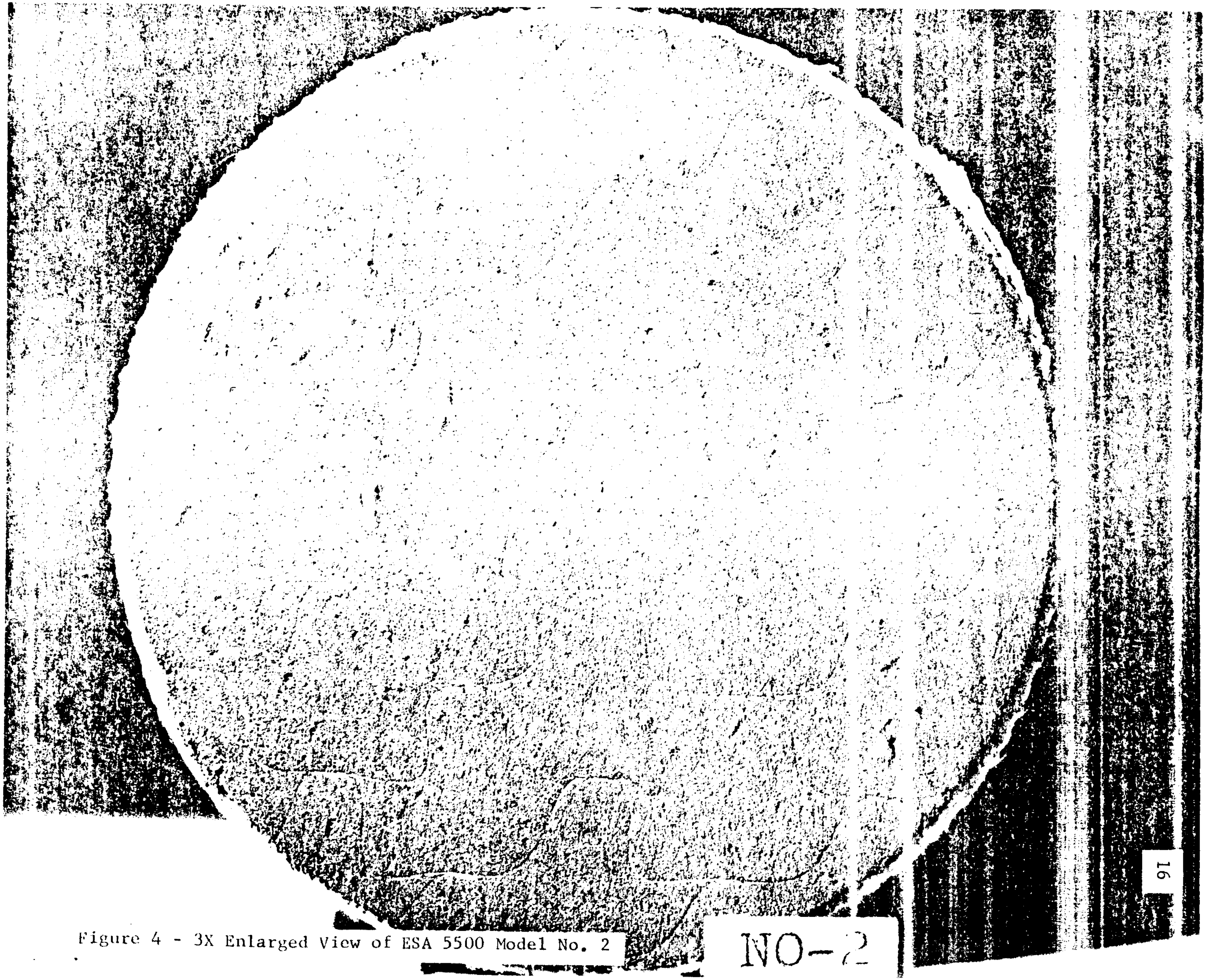


Figure 4 - 3X Enlarged View of ESA 5500 Model No. 2

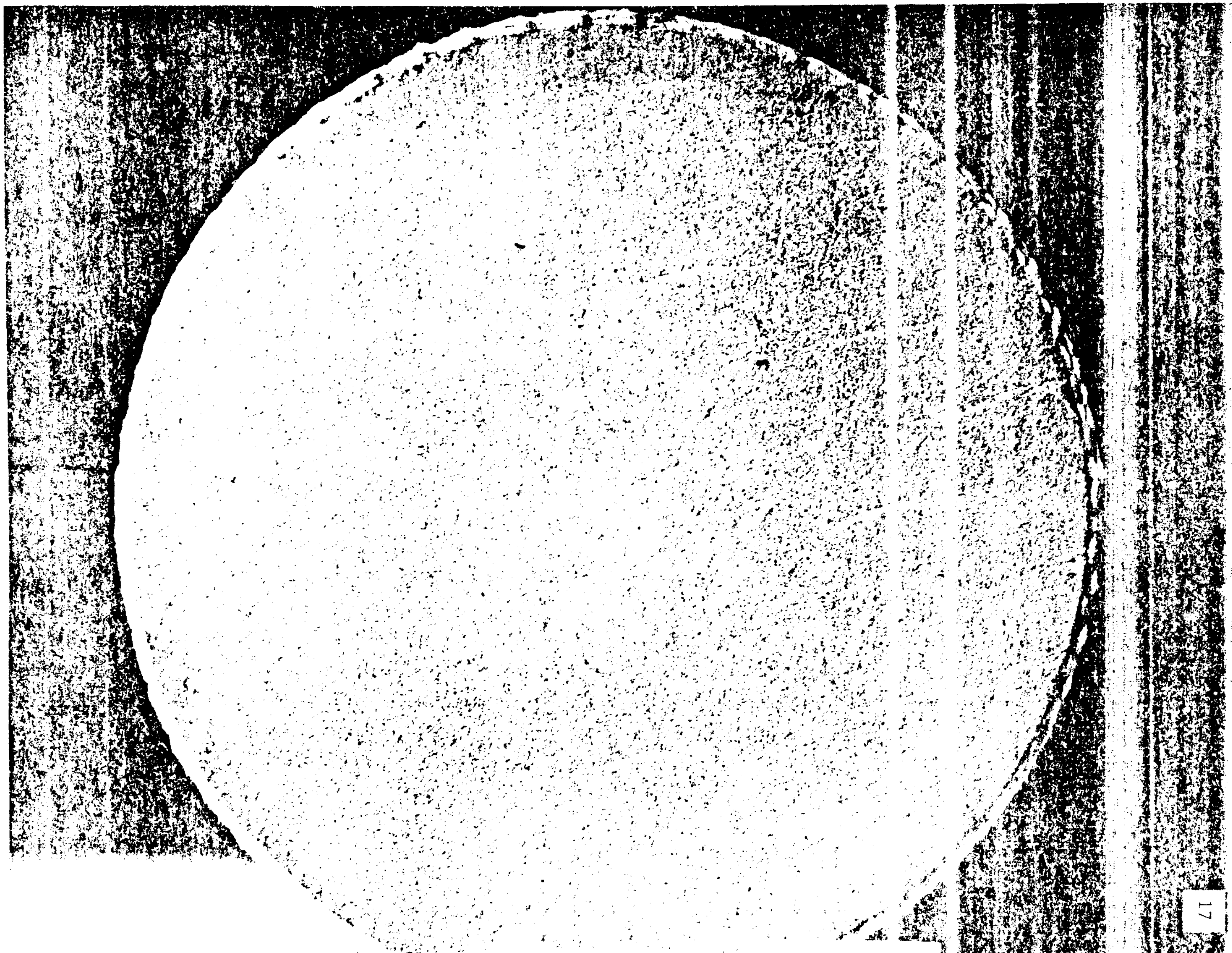


Figure 5 - 3X Enlarged View of ESA 3560 Model No. 3

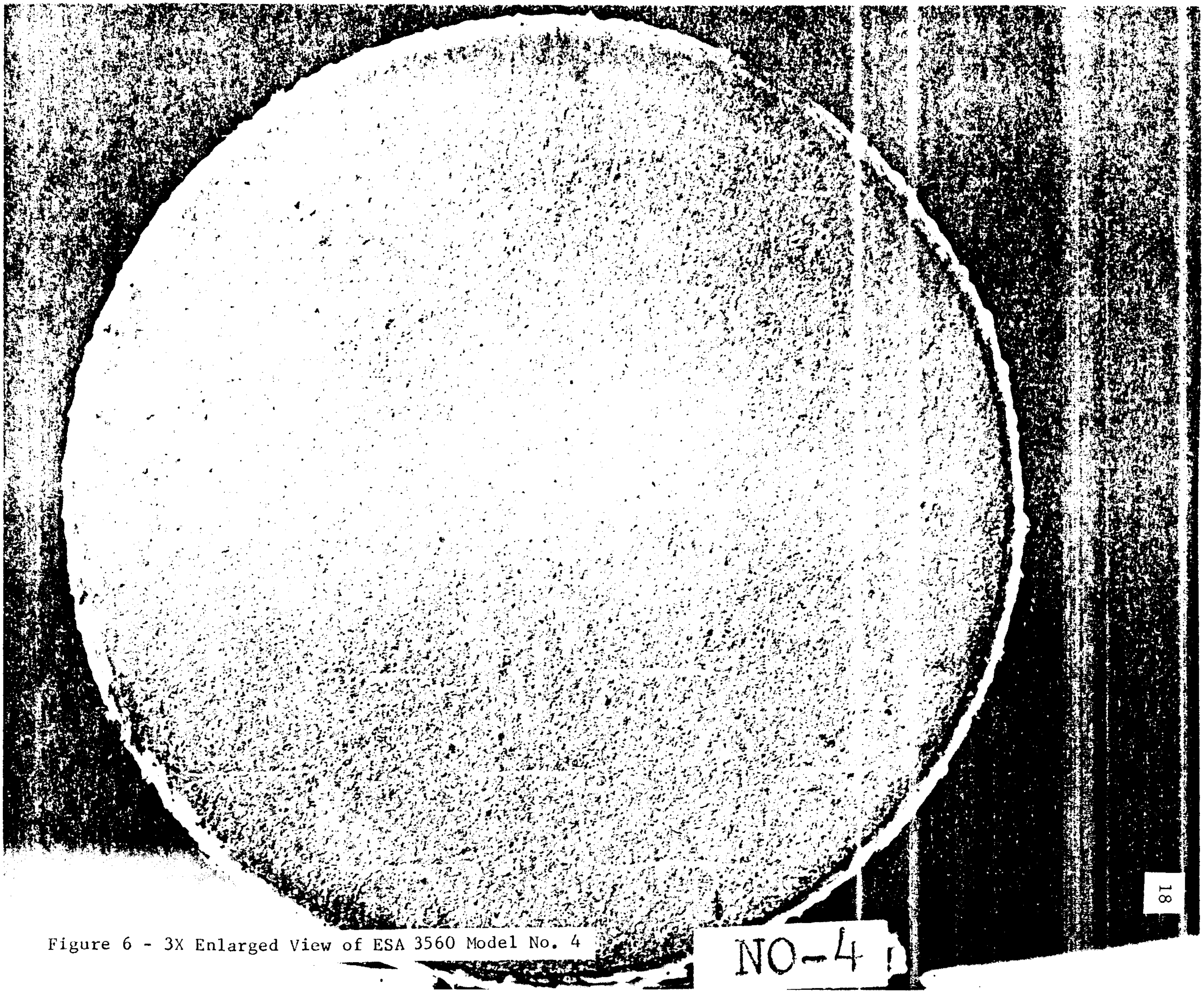


Figure 6 - 3X Enlarged View of ESA 3560 Model No. 4

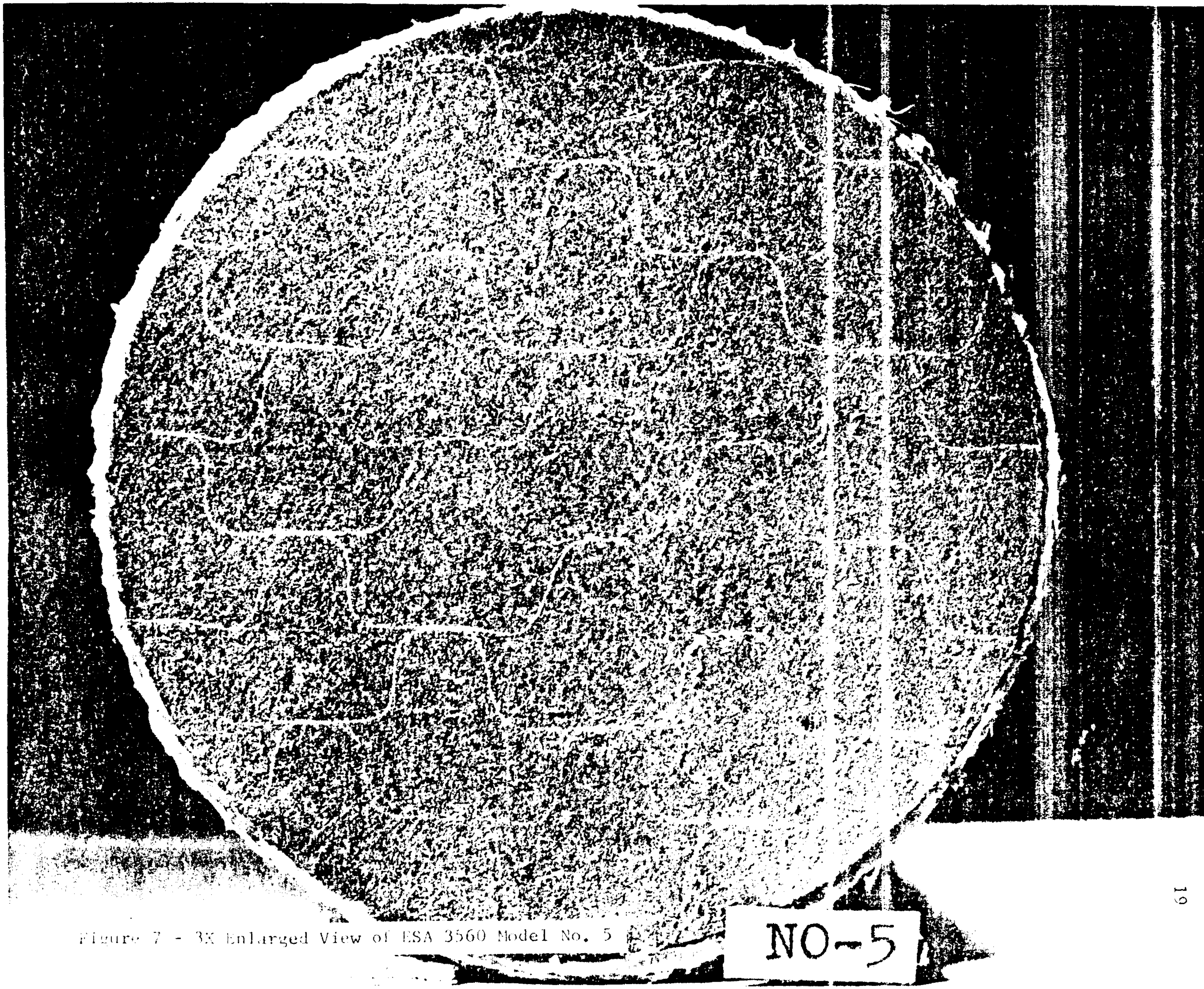


Figure 7 - 3X Enlarged View of ESA 3560 Model No. 5

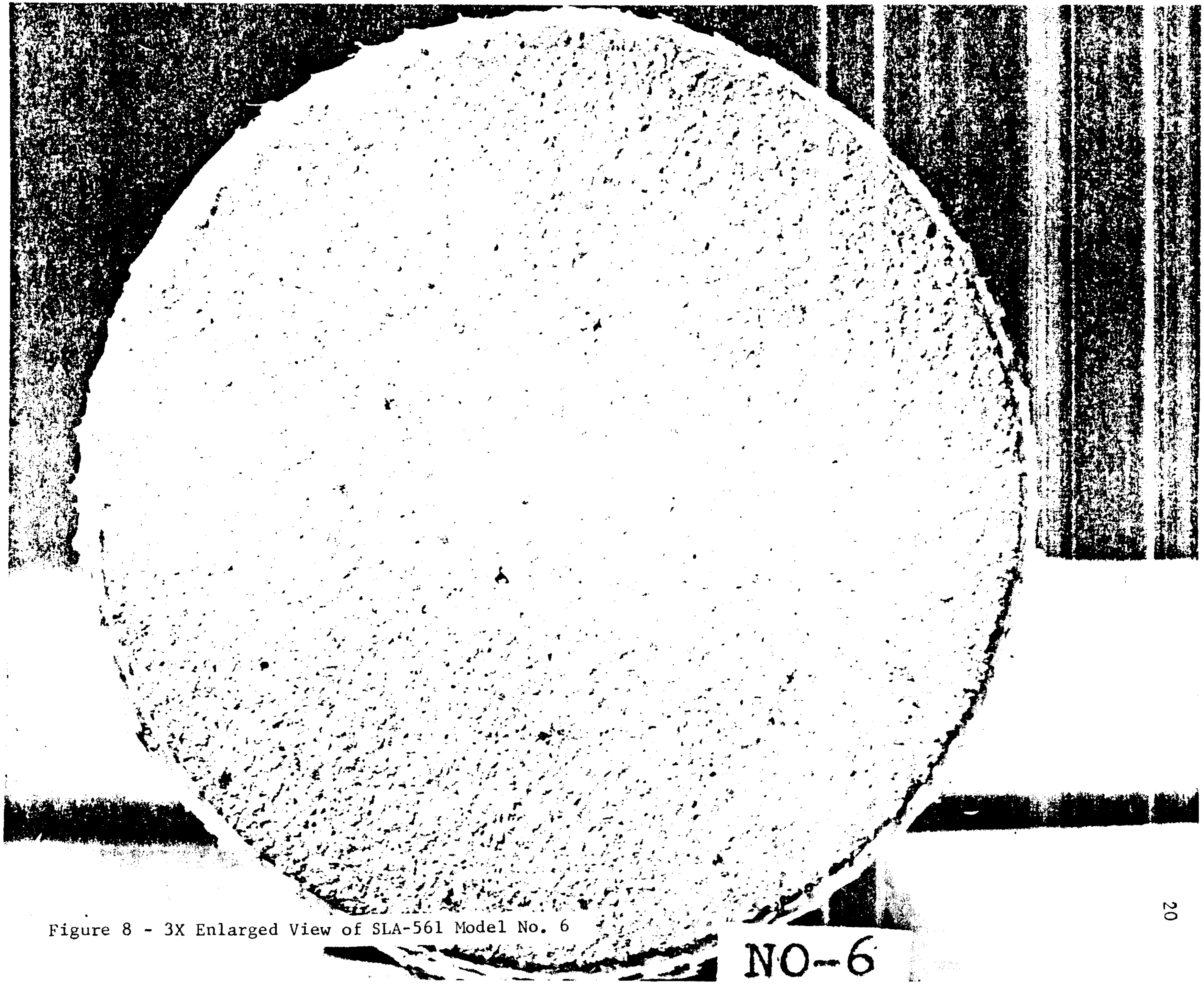


Figure 8 - 3X Enlarged View of SLA-561 Model No. 6

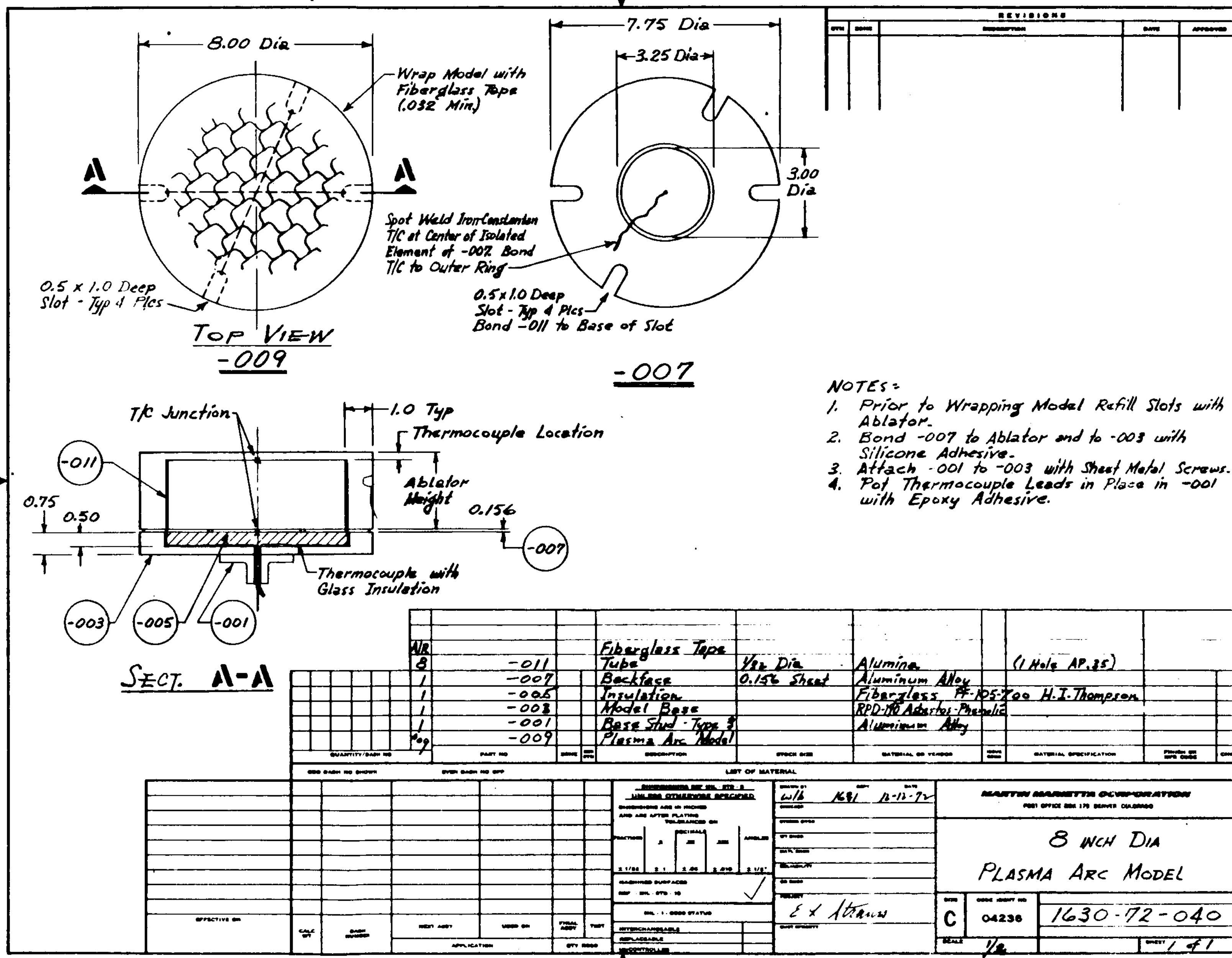


Figure 9 - 8-Inch Diameter Plasma Arc Model

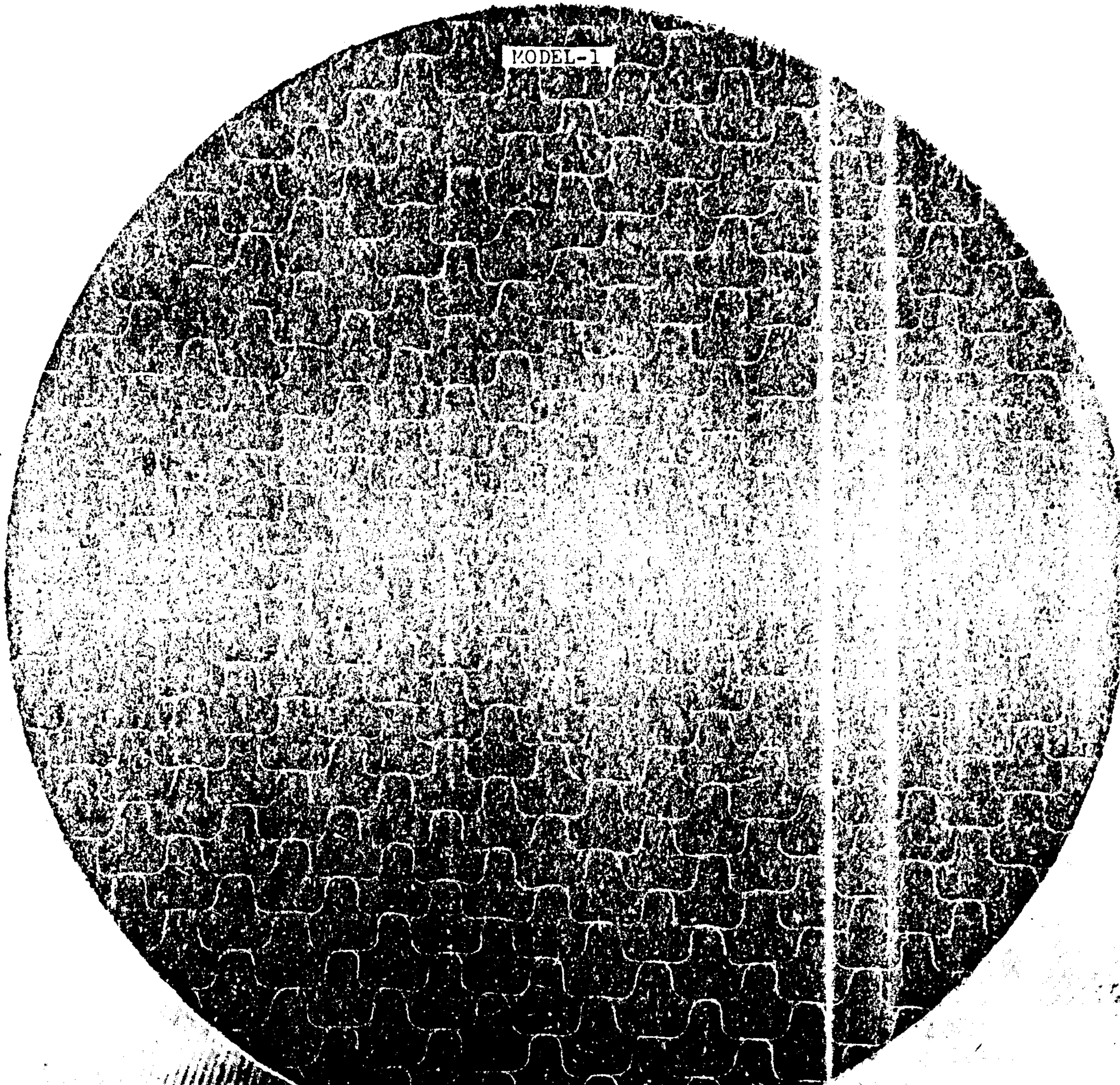


Figure 10 - Surface of 8-Inch Model No. 1 - ESA 3560-

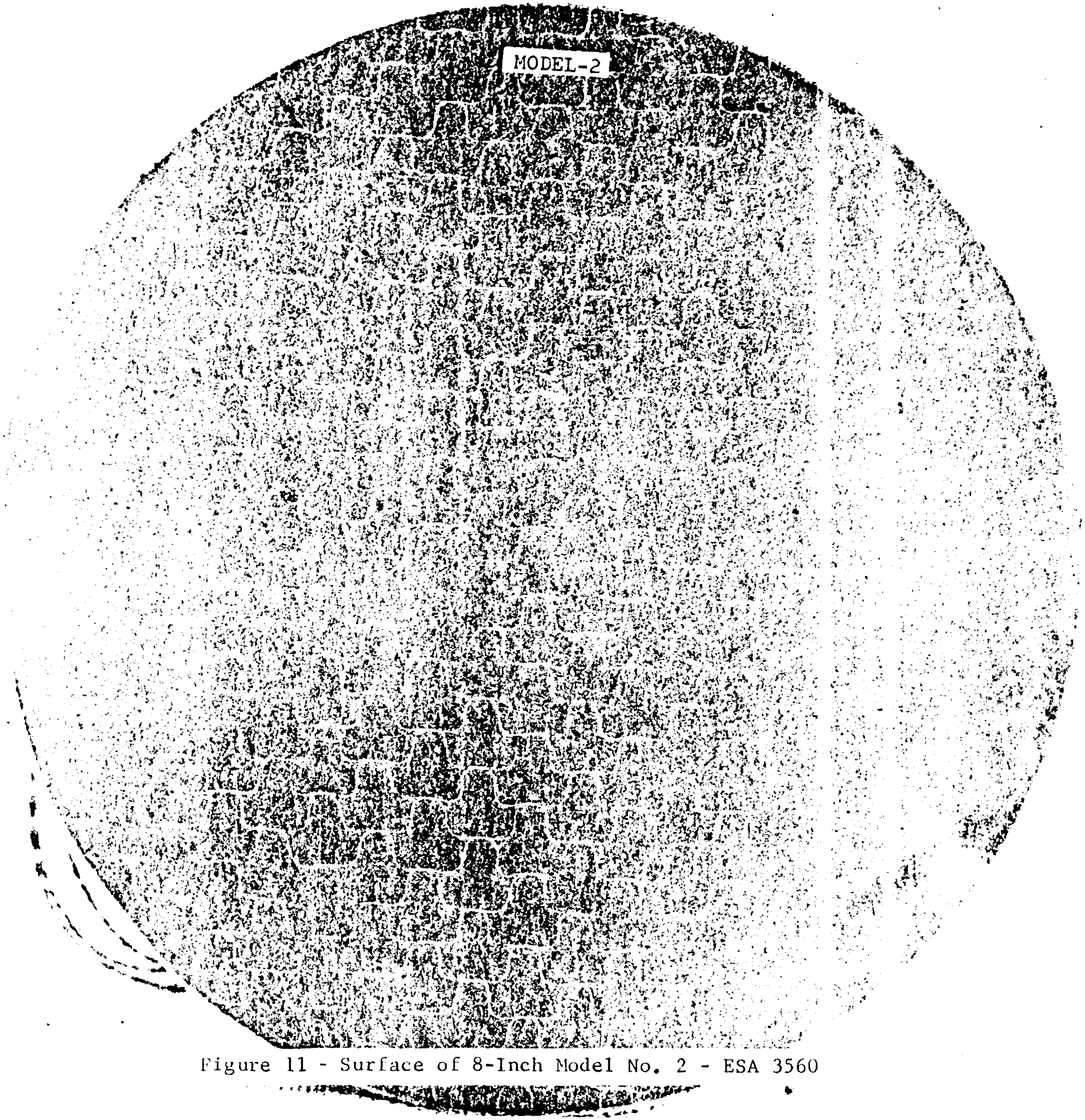


Figure 11 - Surface of 8-Inch Model No. 2 - ESA 3560

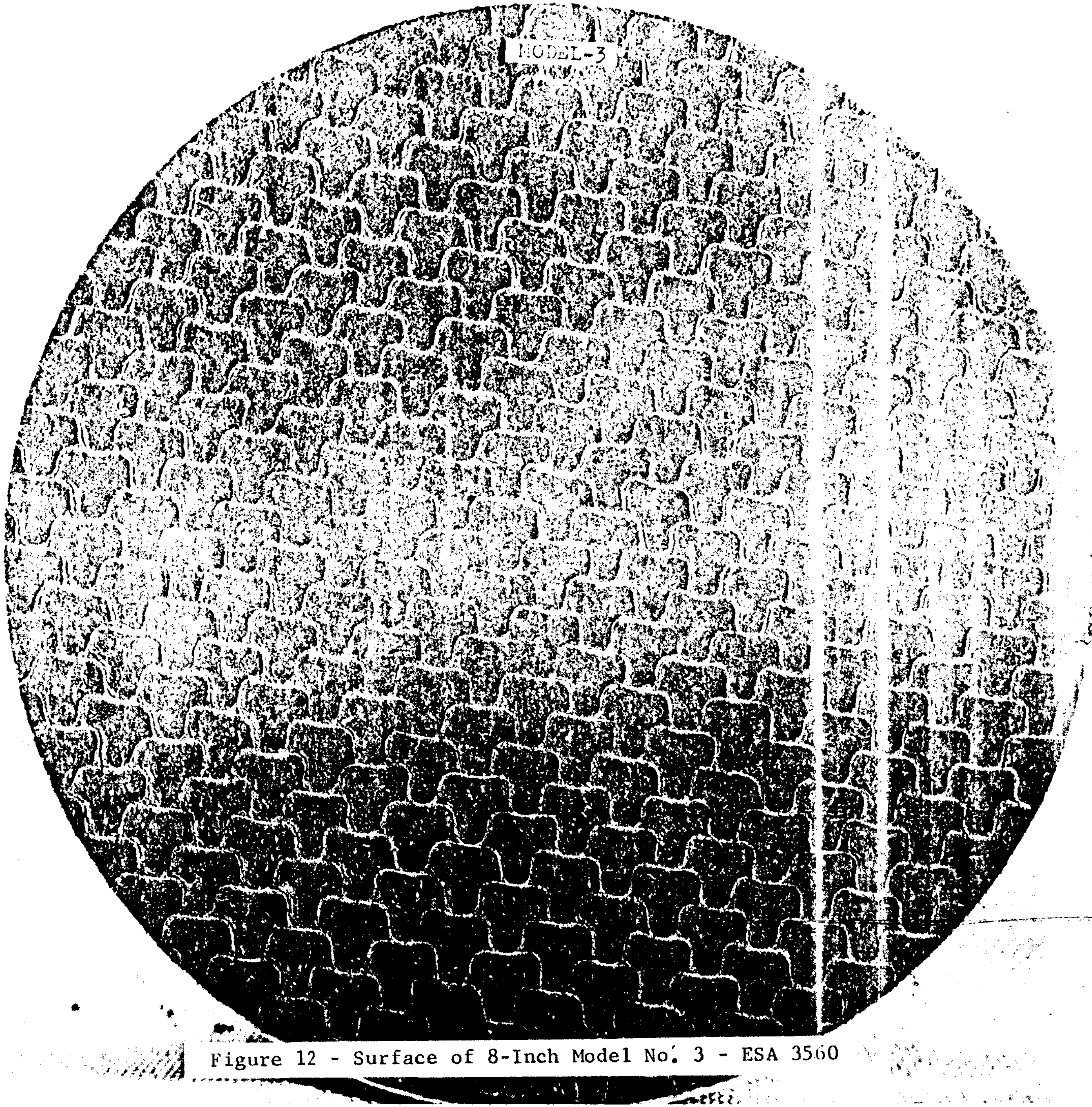


Figure 12 - Surface of 8-Inch Model No. 3 - ESA 3560

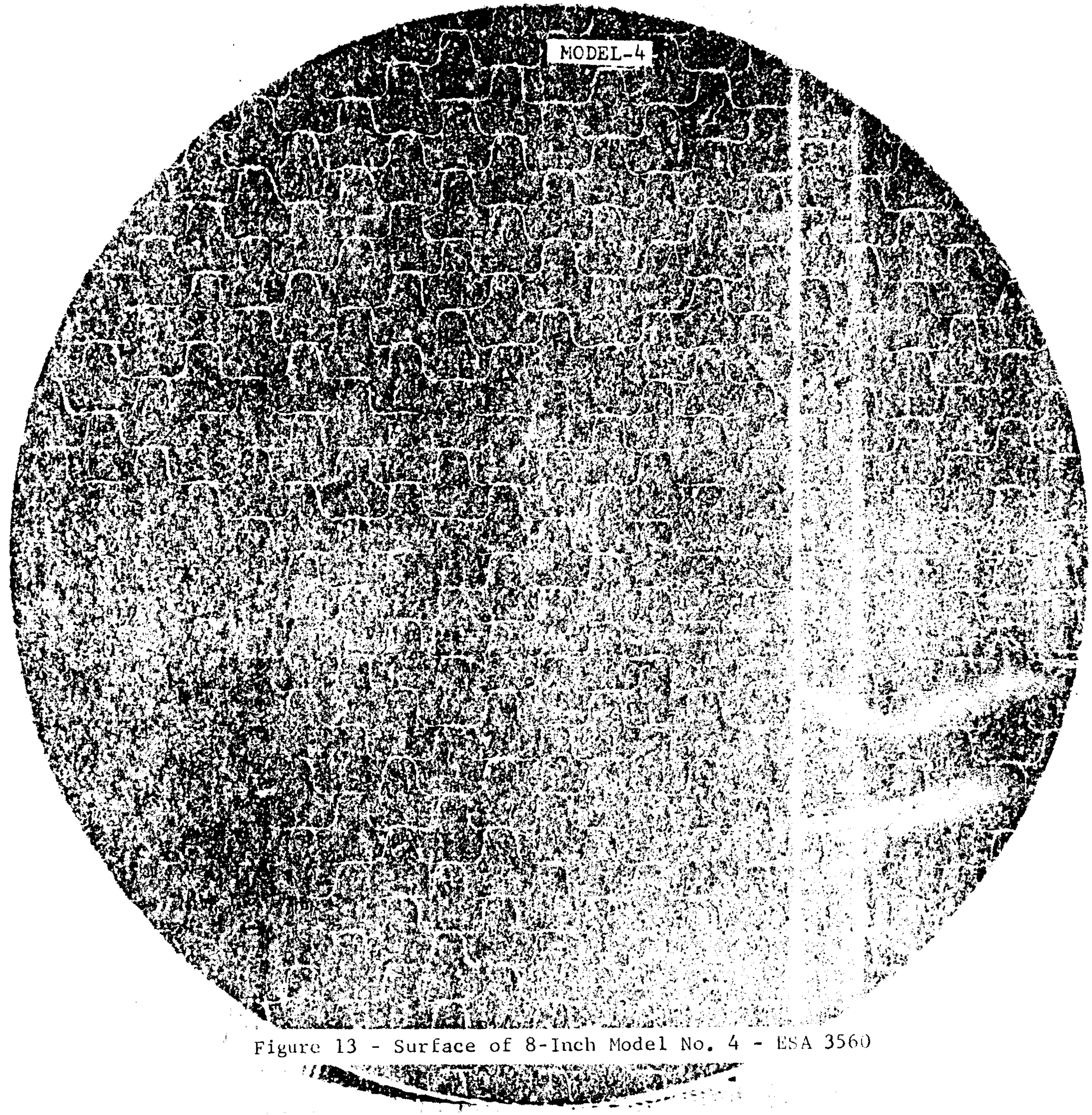


Figure 13 - Surface of 8-Inch Model No. 4 - ESA 3560

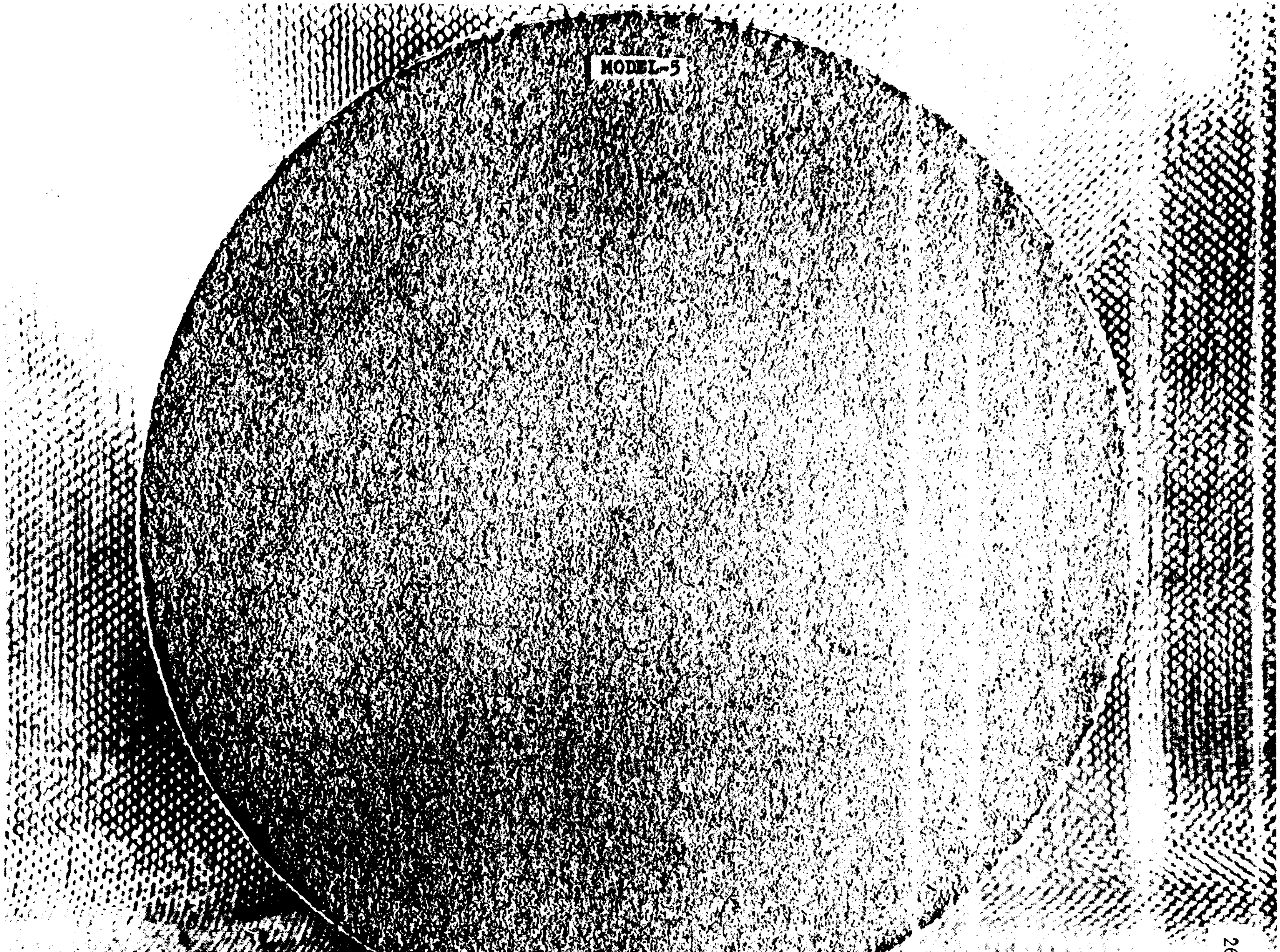


Figure 14 - Surface of 8-Inch Model No. 5 - SLA-561

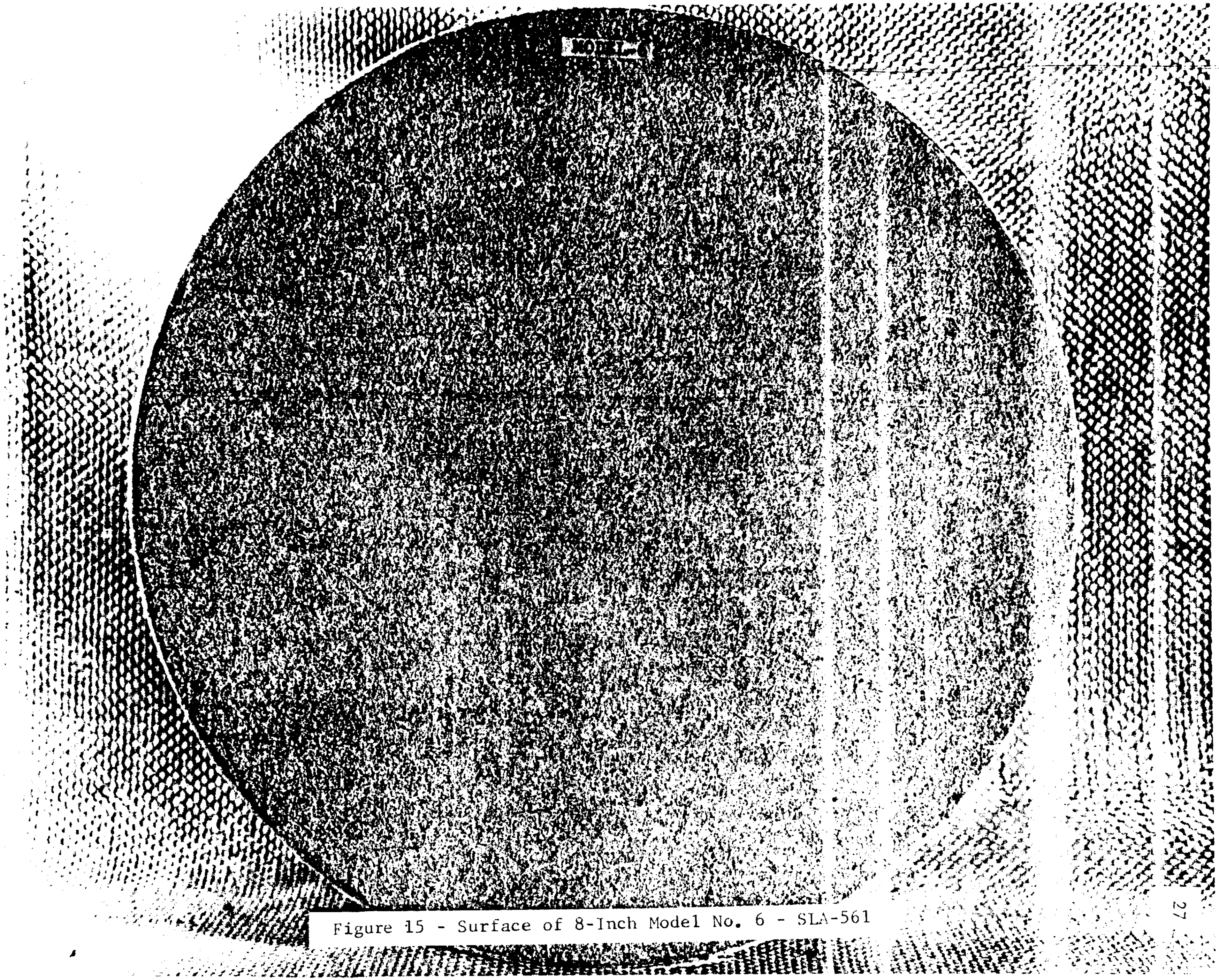


Figure 15 - Surface of 8-Inch Model No. 6 - SLA-561

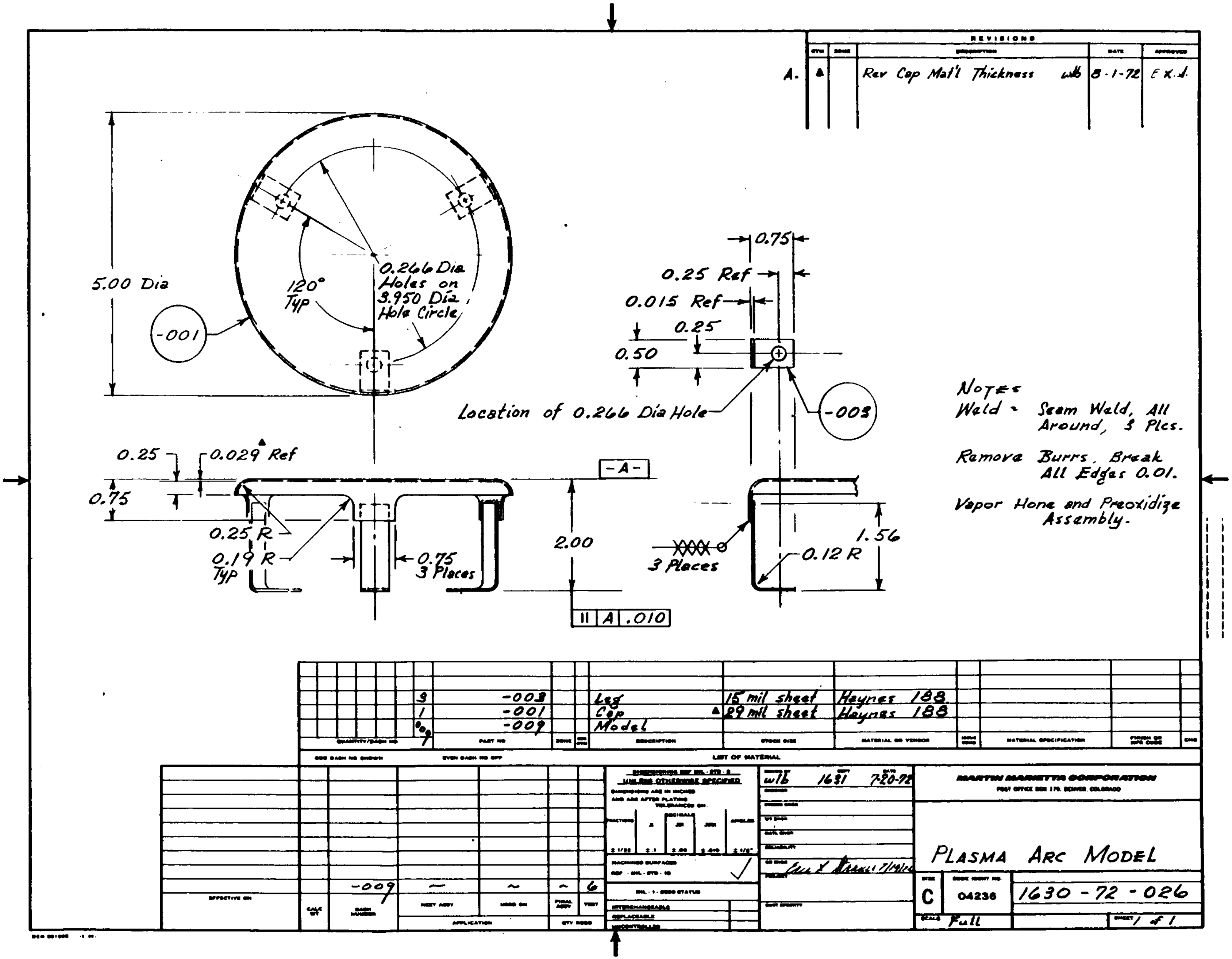


Figure 16 - Haynes-188 Plasma Arc Model

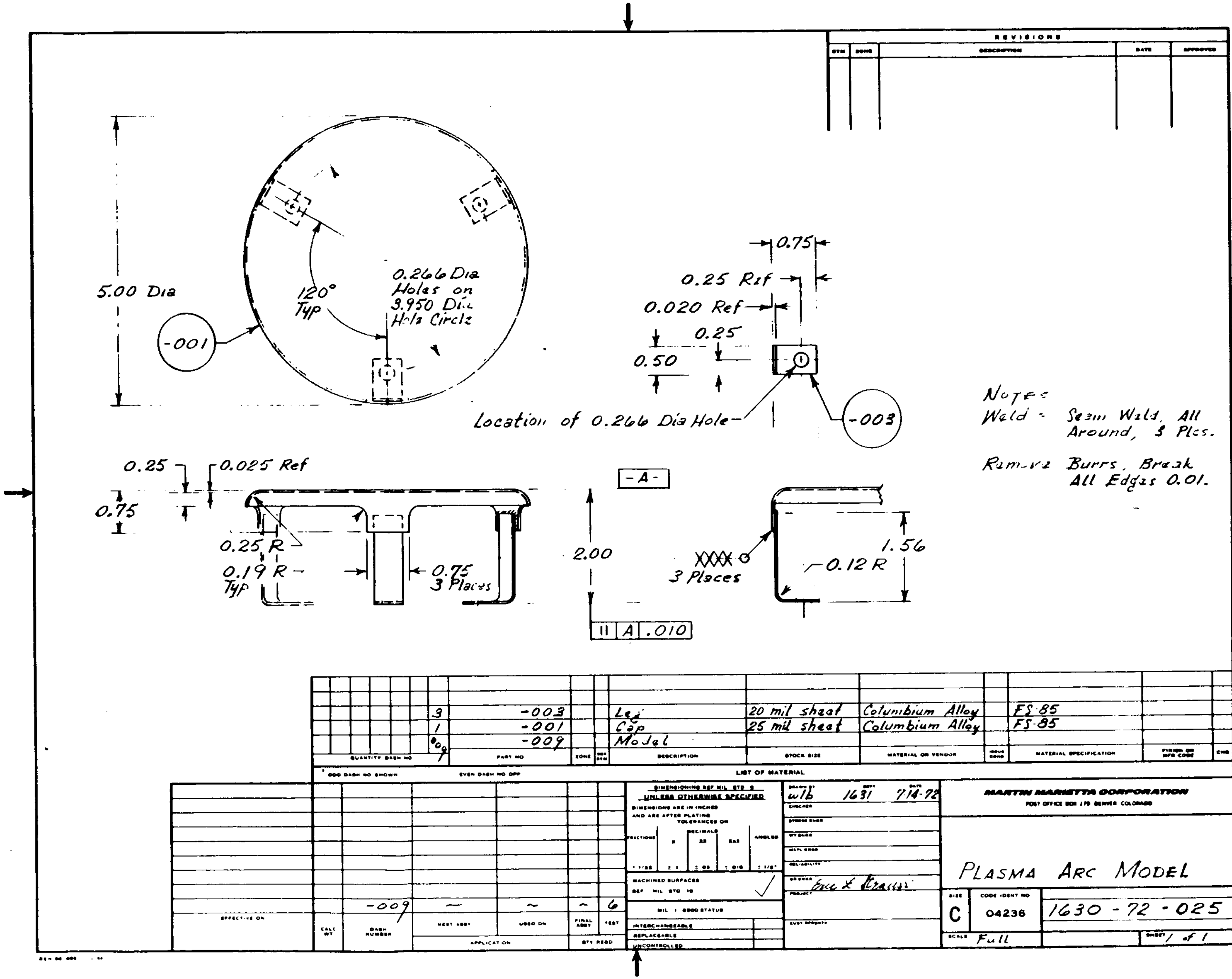


Figure 17 - FS-85 Columbium Plasma Arc Model

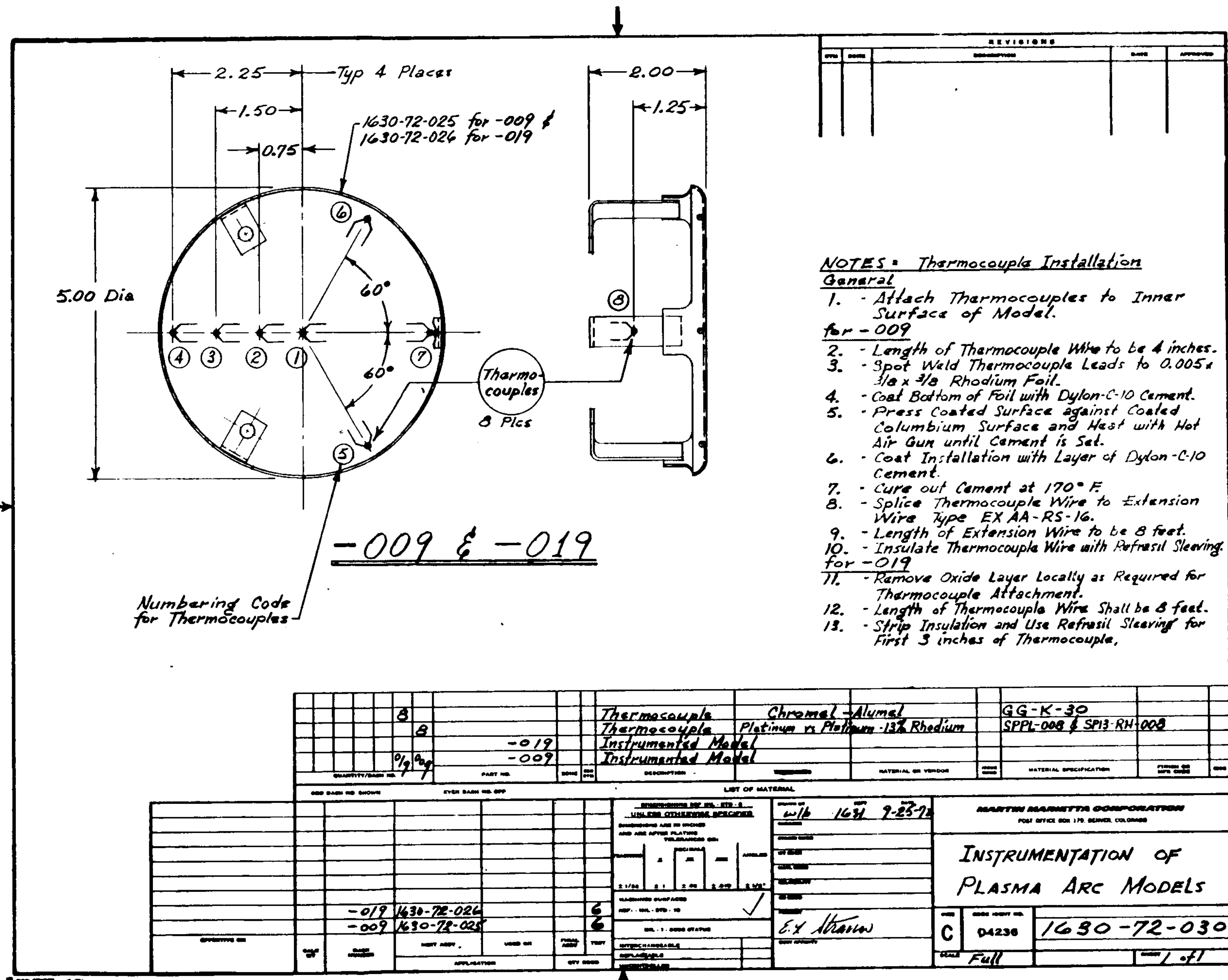


Figure 18 - Thermocouple Instrumentation for Metallic Plasma Arc Models

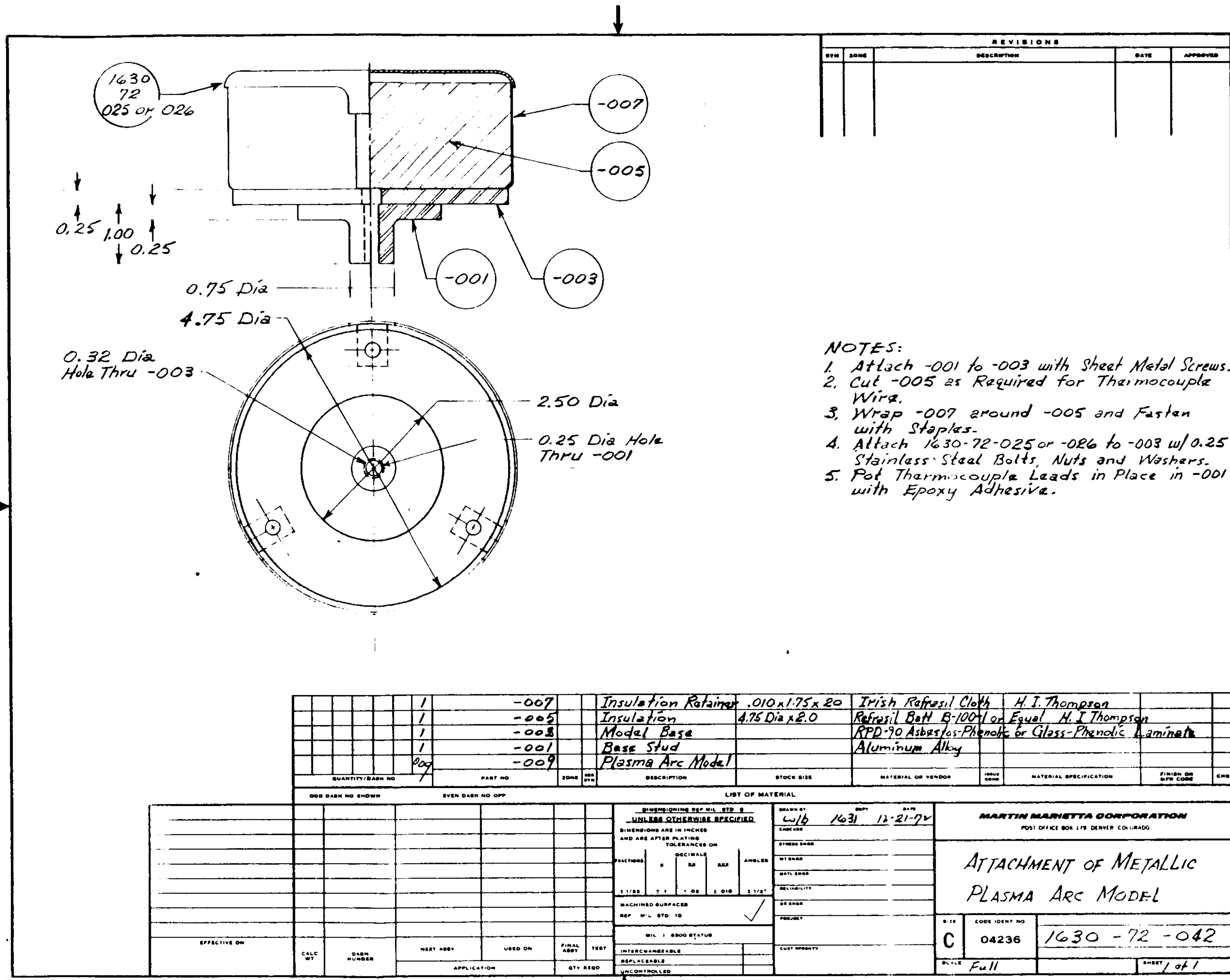


Figure 19 - Test Installation for Metallic Plasma Arc Models

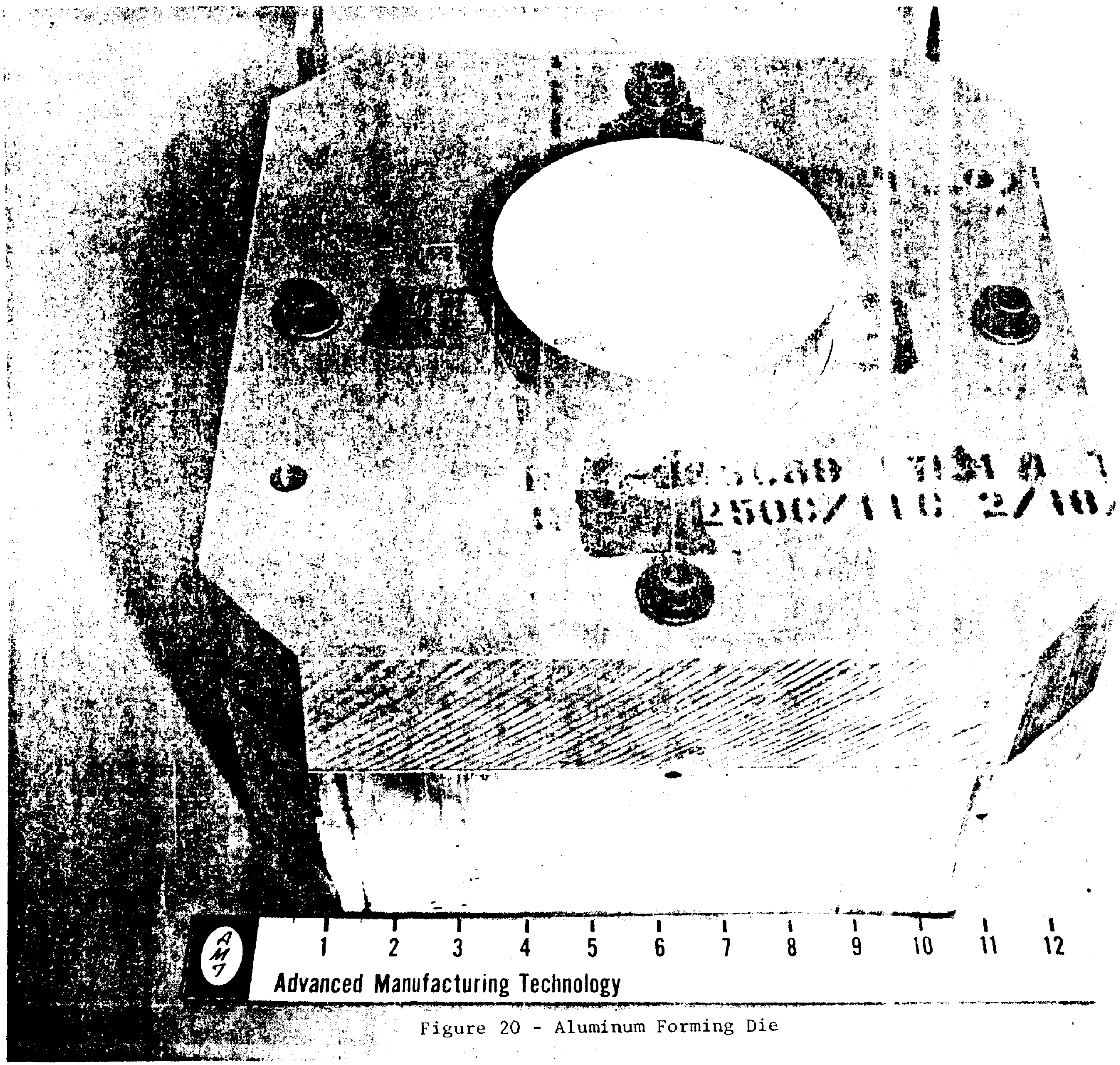


Figure 20 - Aluminum Forming Die

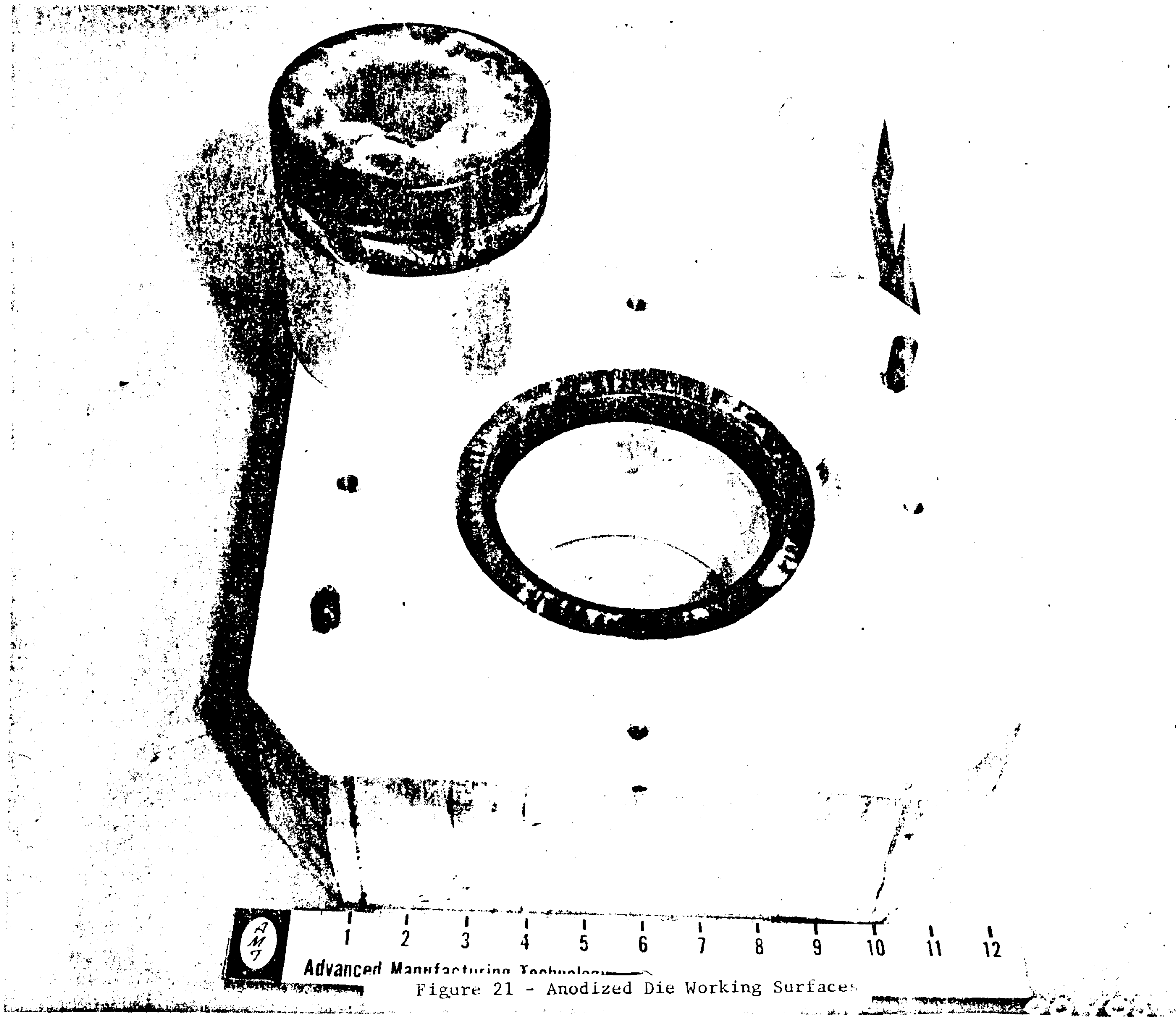


Figure 21 - Anodized Die Working Surfaces

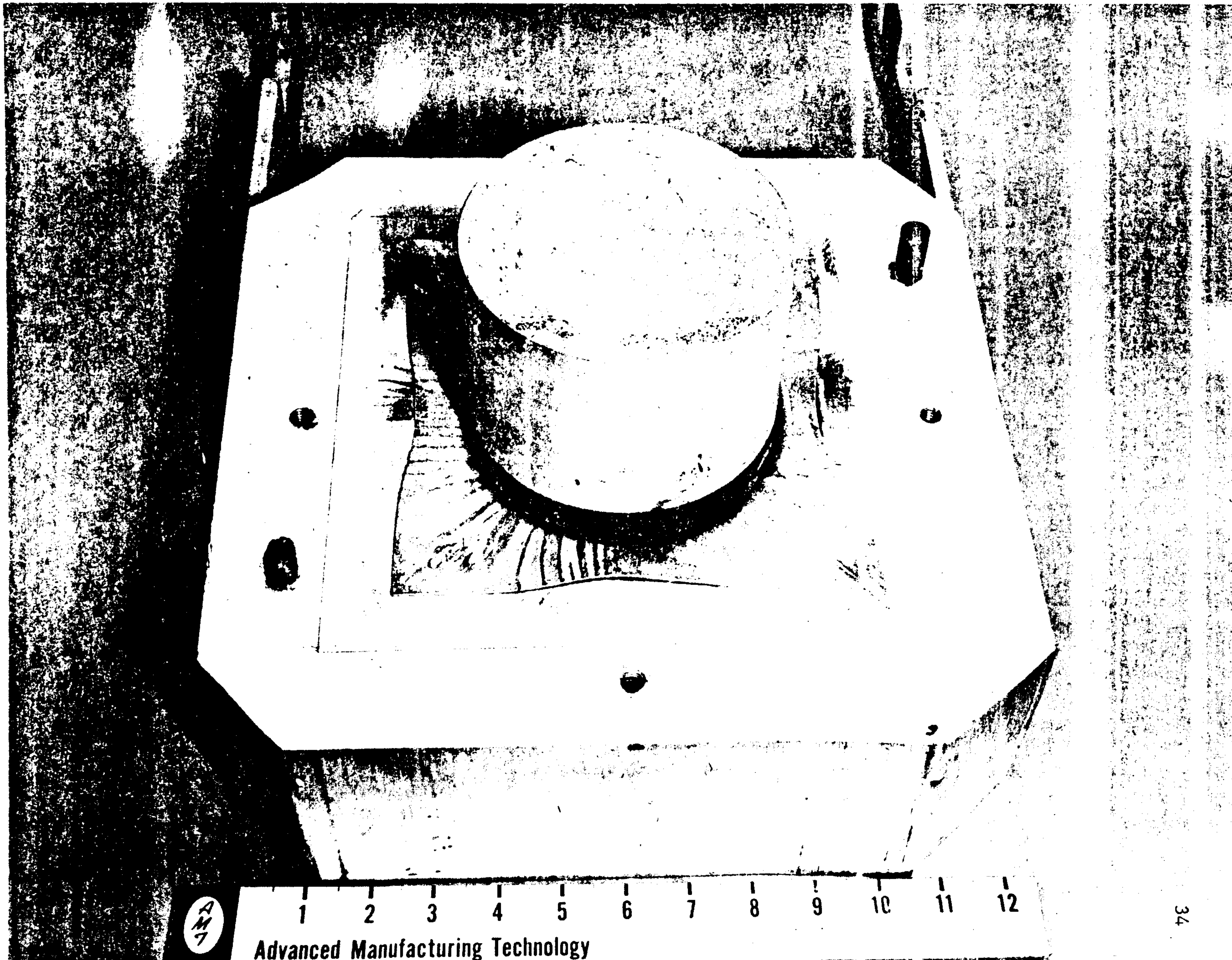


Figure 22 - Formed HS-188 Blank in Die Cavity

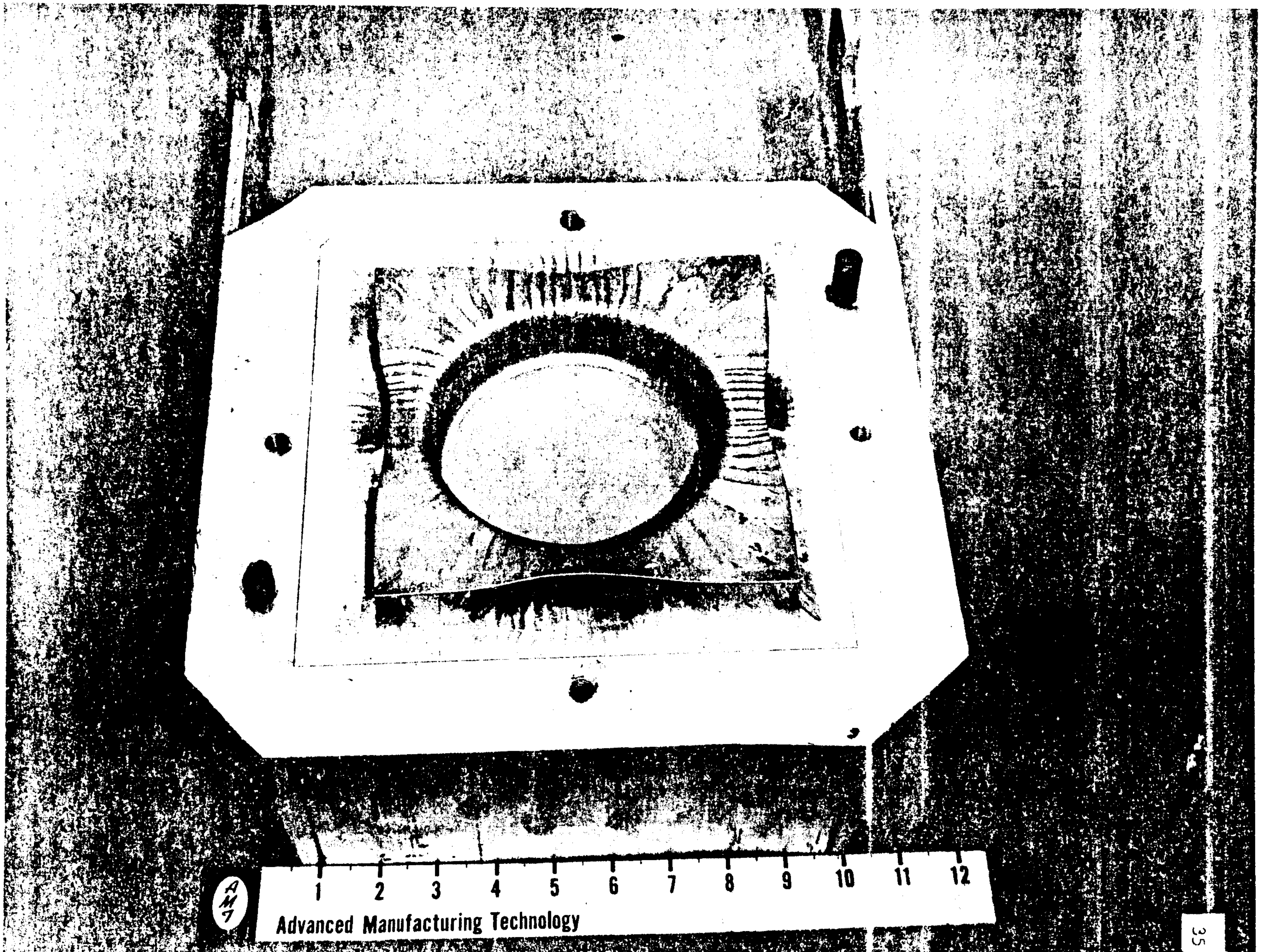


Figure 23 - Formed HS 188 Blank

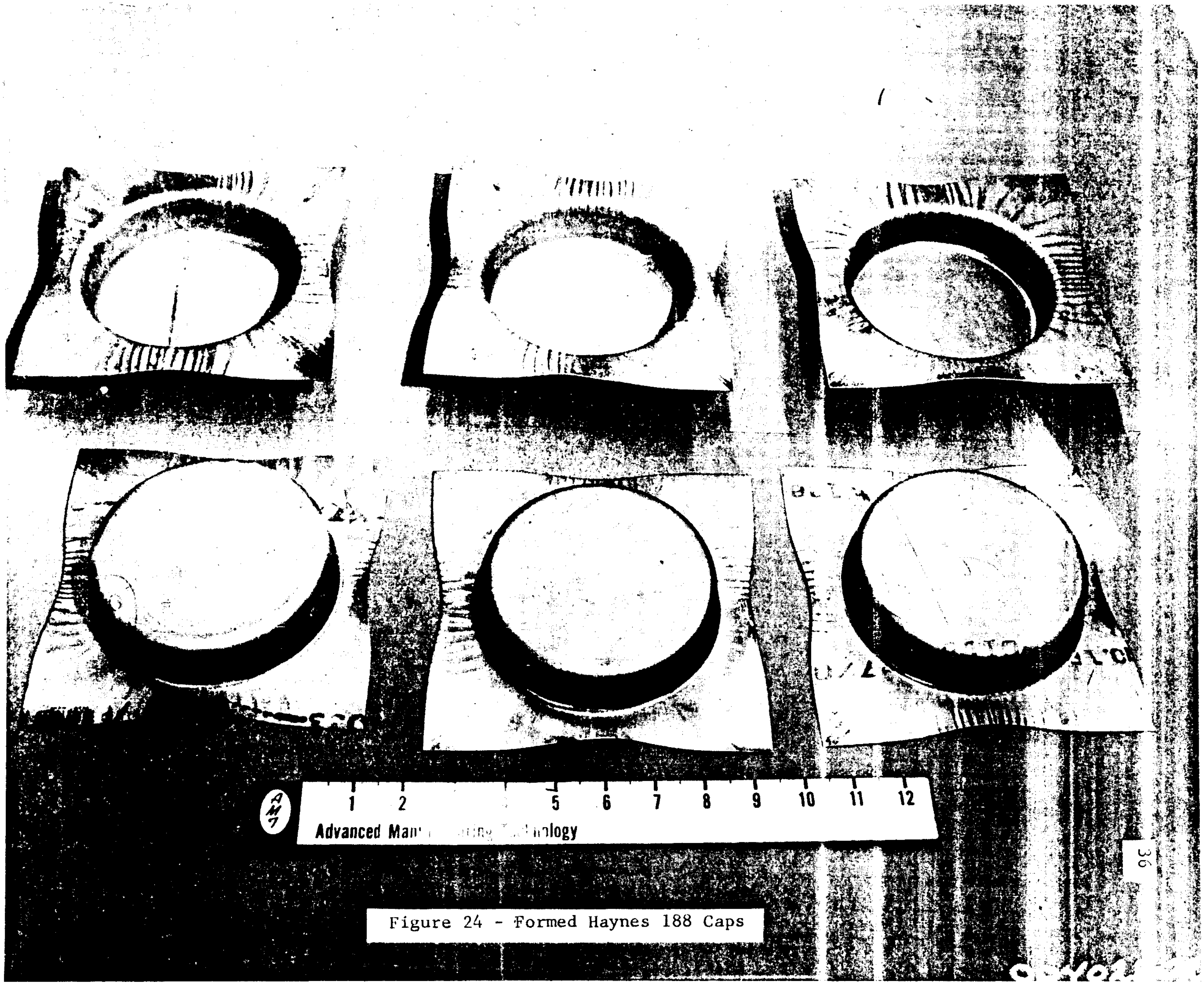


Figure 24 - Formed Haynes 188 Caps

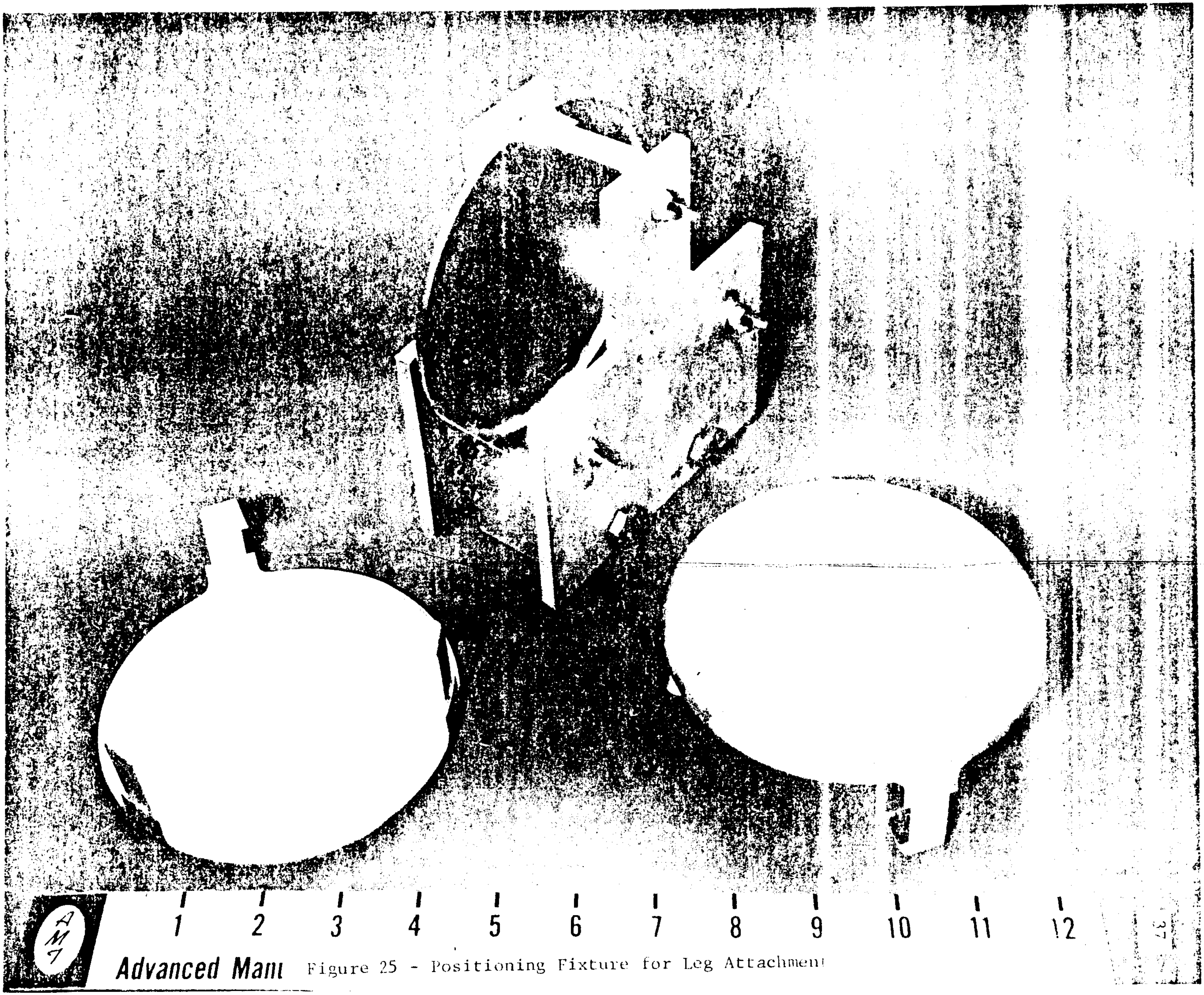


Figure 25 - Positioning Fixture for Leg Attachment

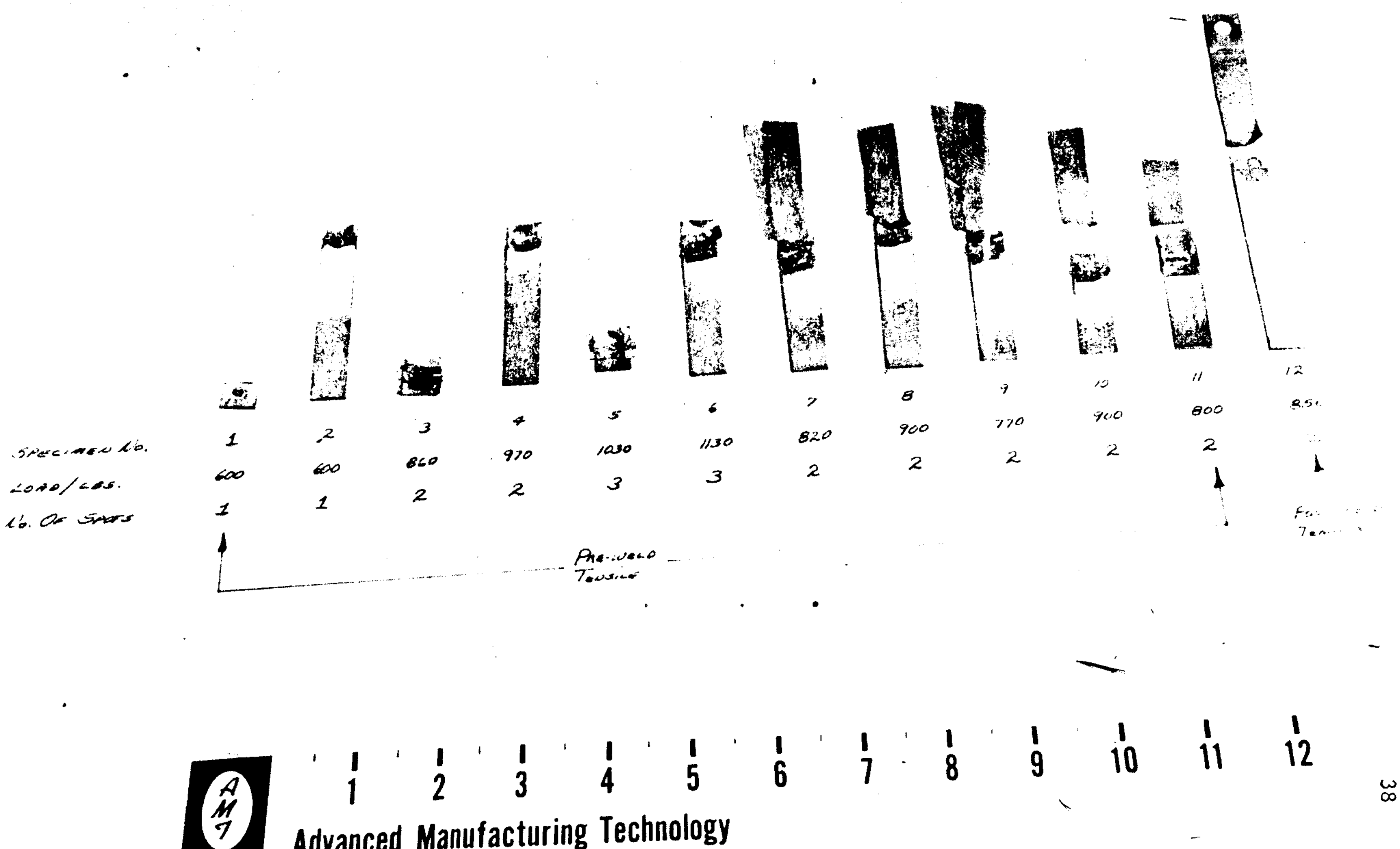


Figure 26 - Weld Test Coupons

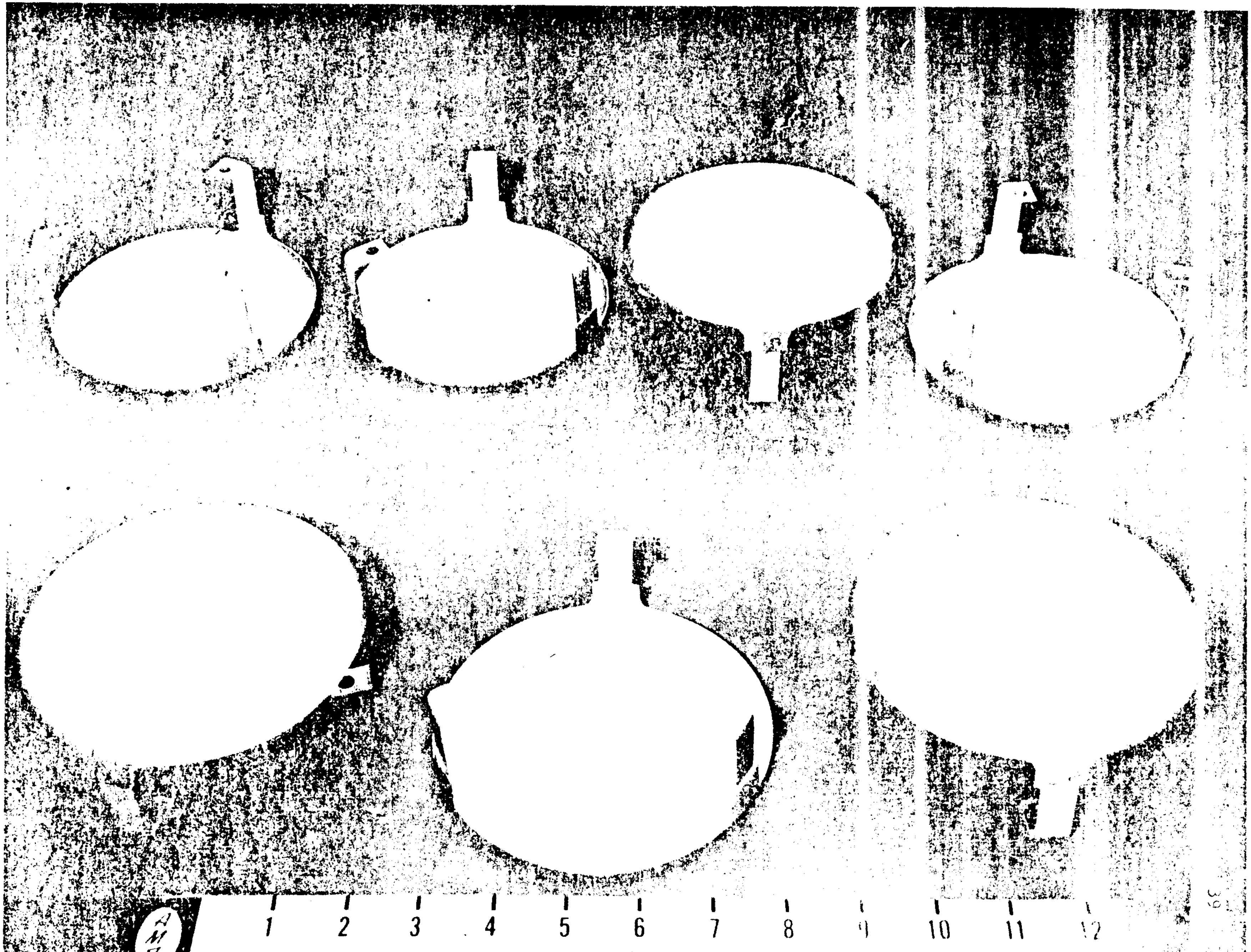


Figure 27 - Haynes 188 Models before Preoxidation

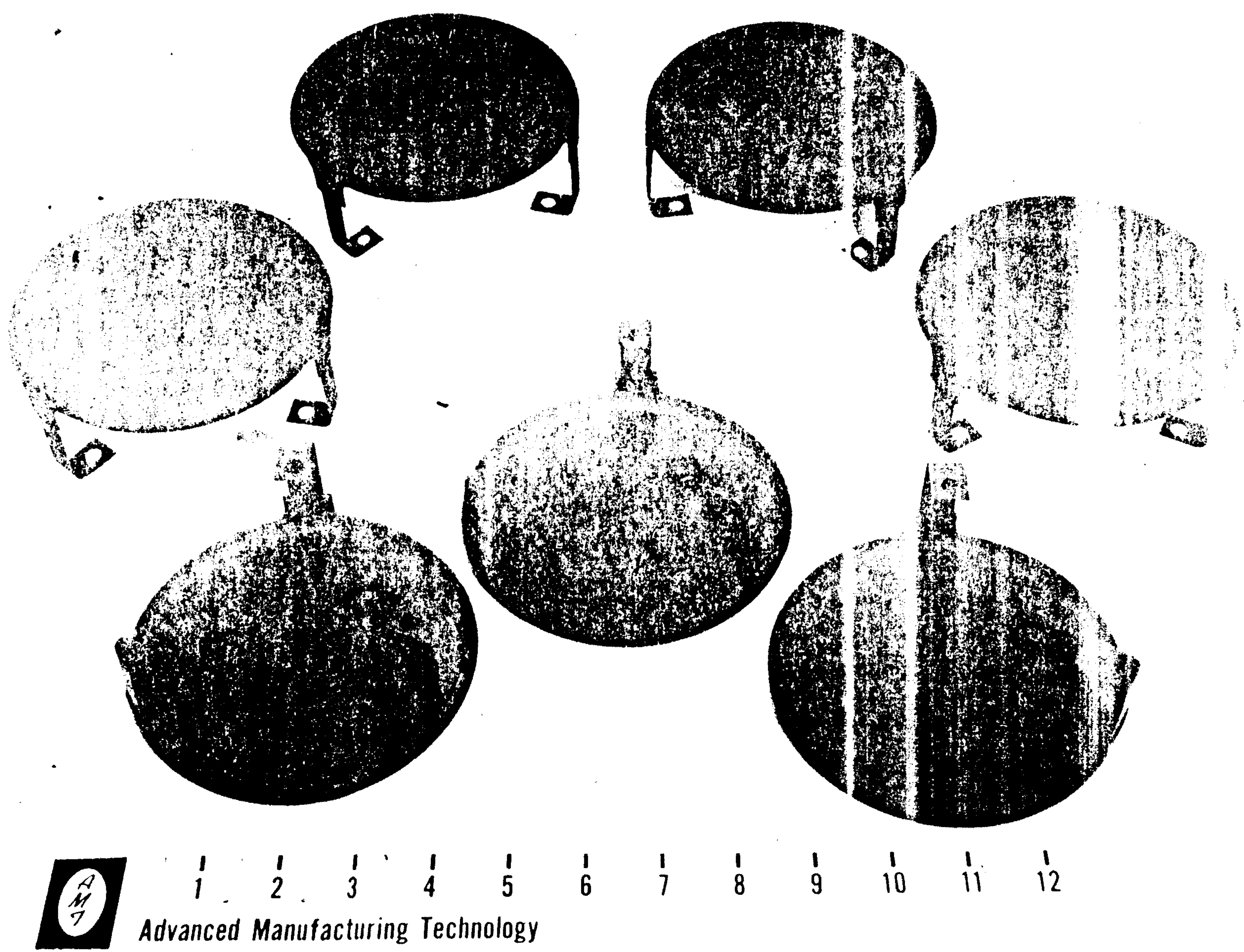


Figure 28 - Haynes 188 Models after Preoxidation

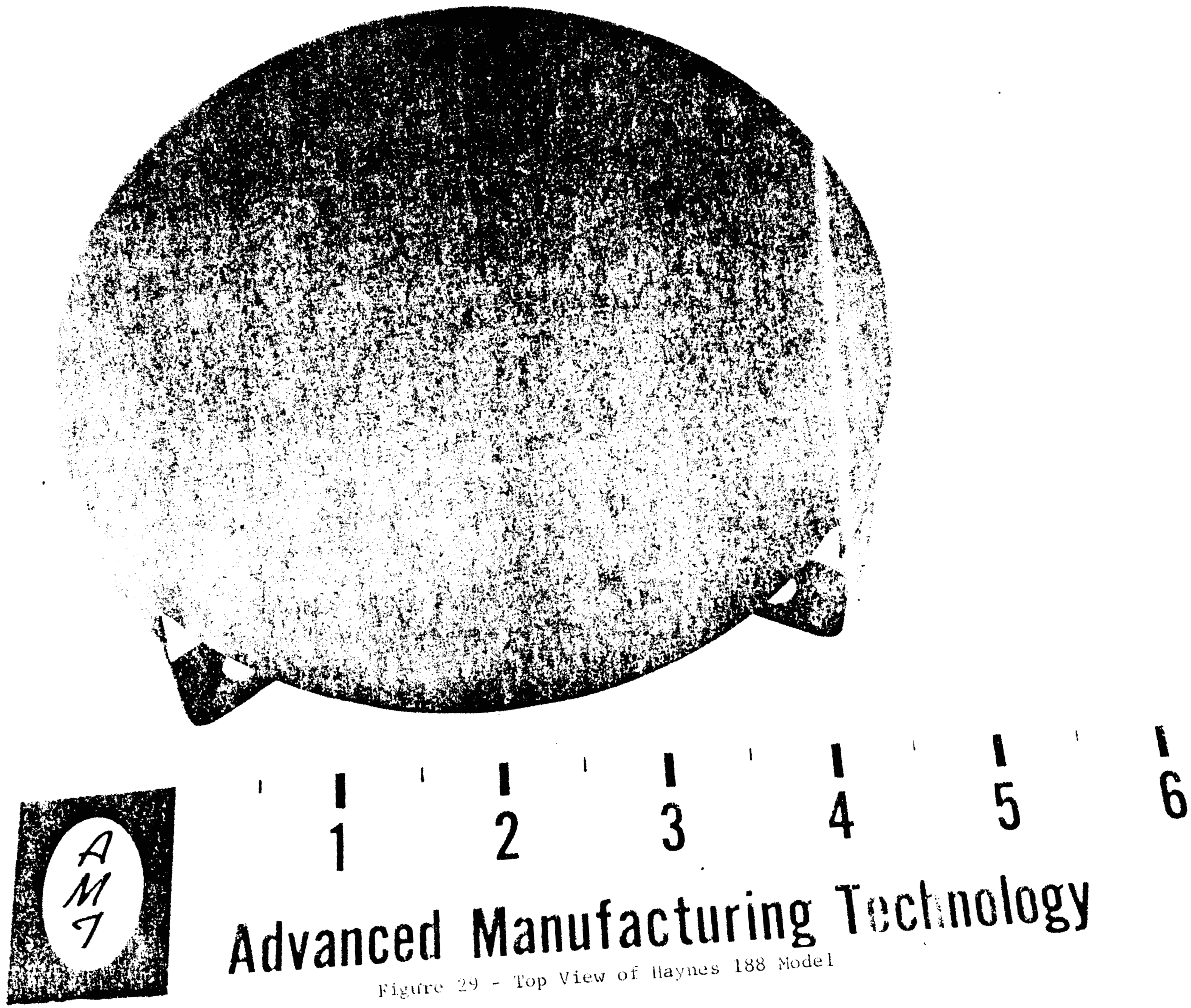


Figure 29 - Top View of Haynes 188 Model

Figure 30 - Bottom View of Haynes 188 Model

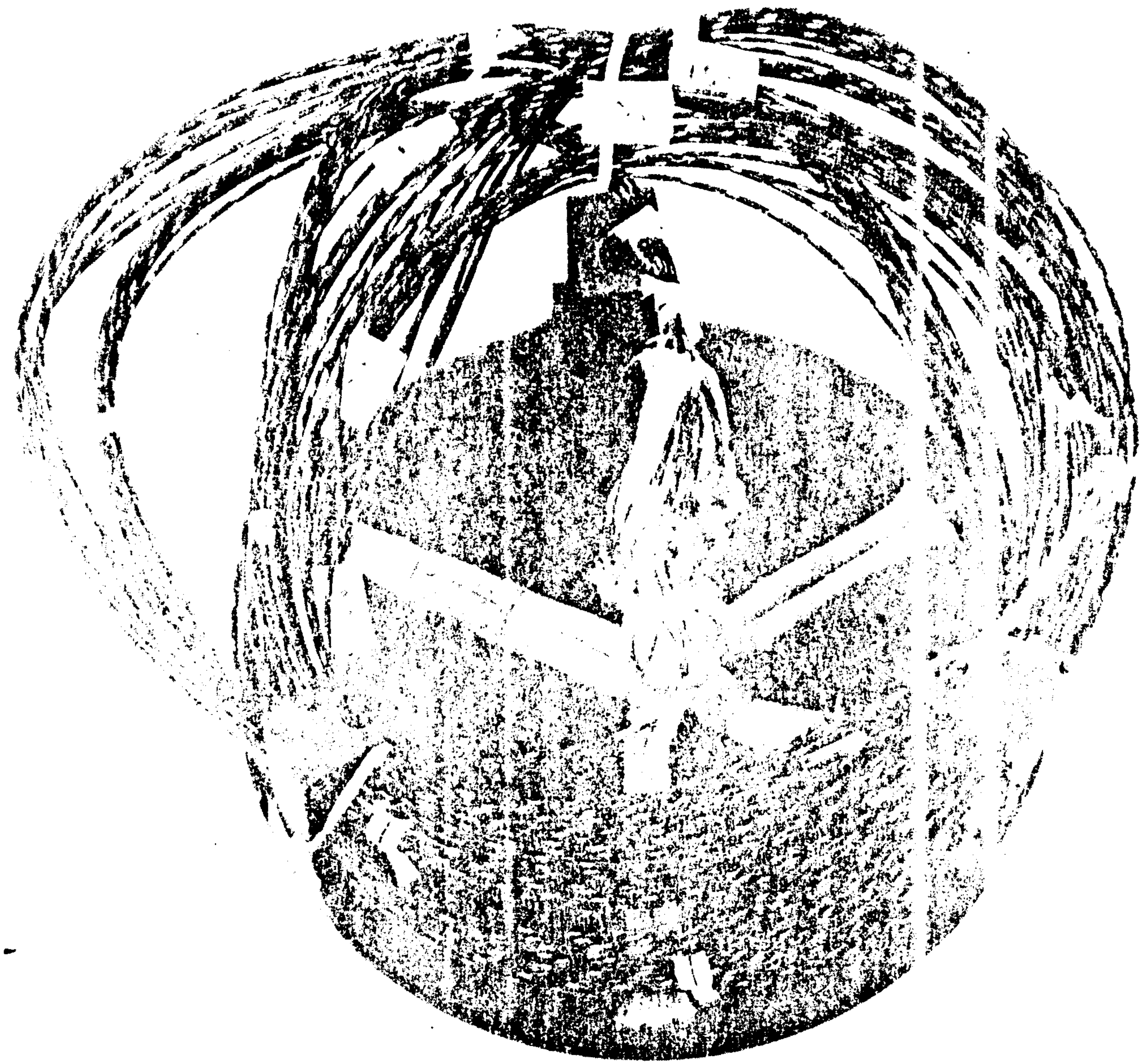


Figure 31 - Instrumented Haynes 188 Model

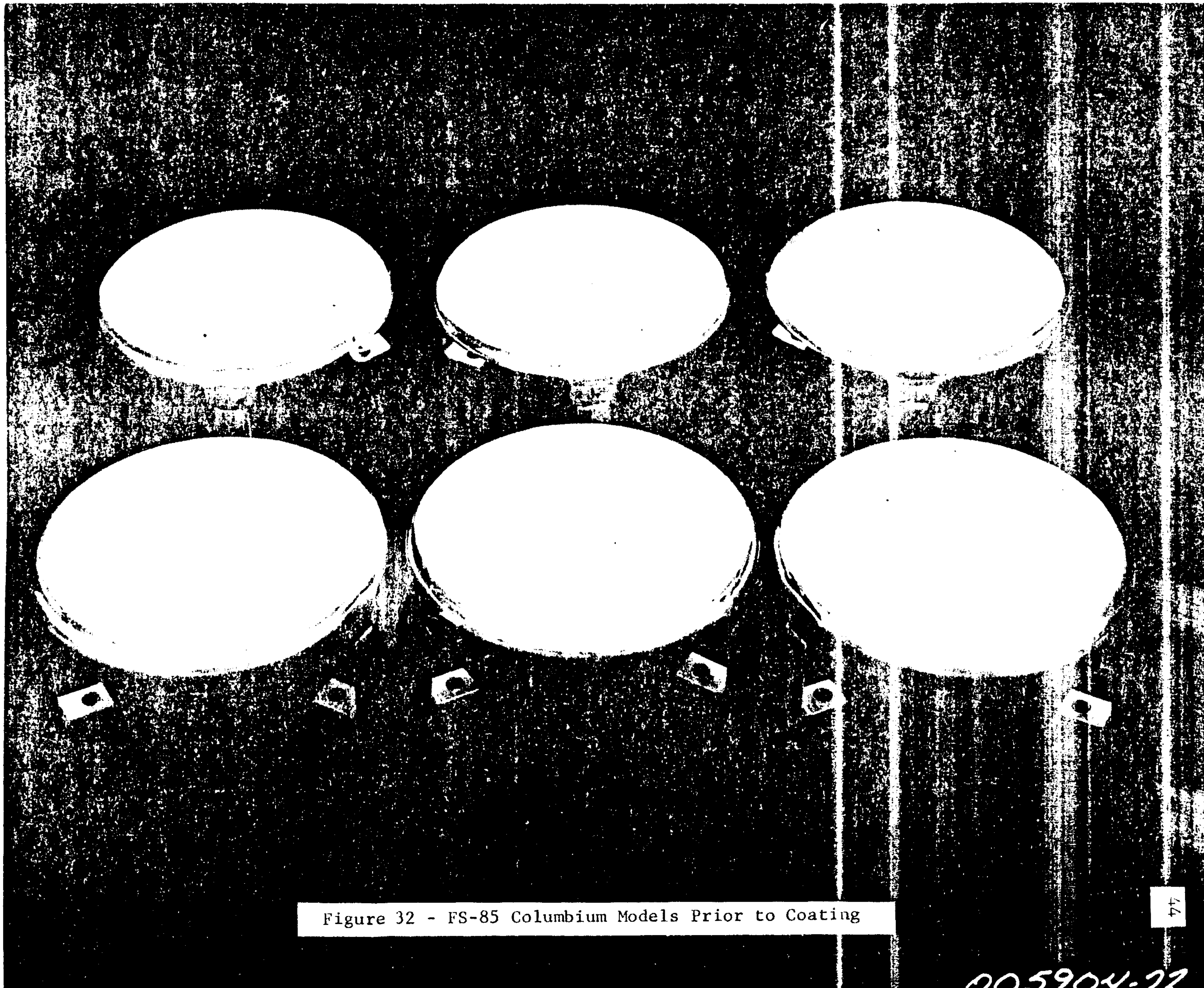


Figure 32 - FS-85 Columbium Models Prior to Coating

005904-72

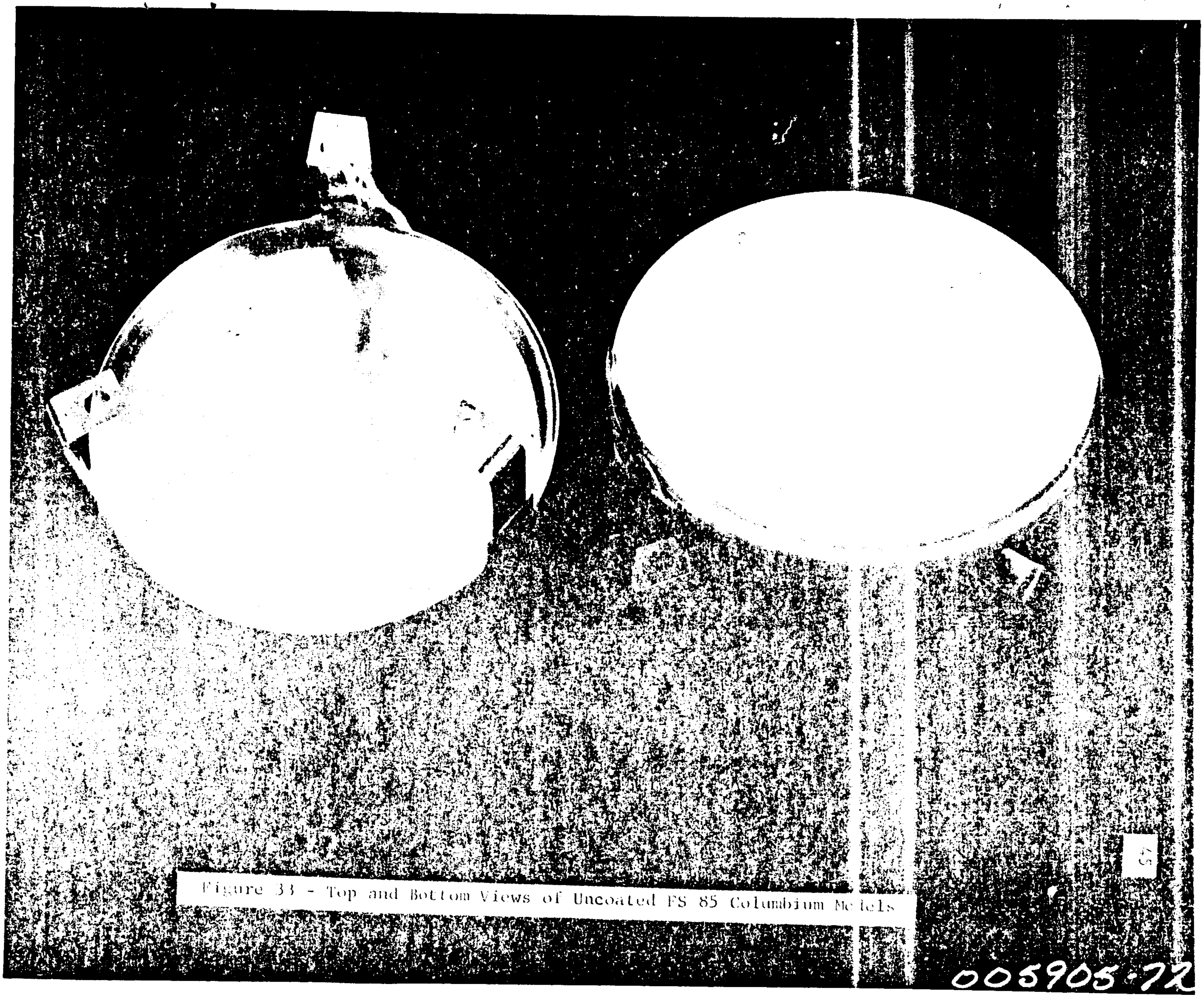


Figure 33 - Top and Bottom Views of Uncoated FS 85 Columbium Models

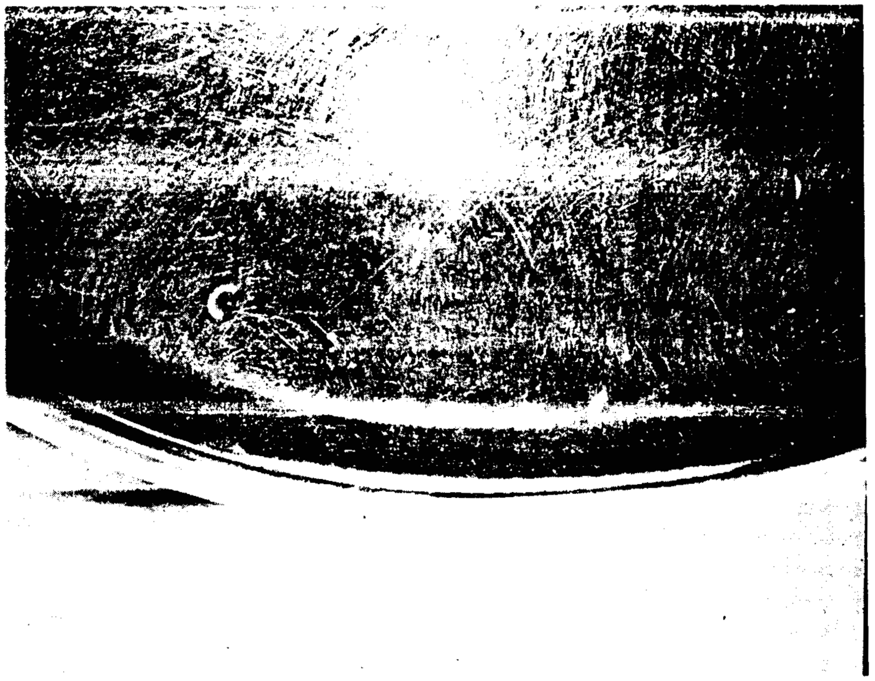


Figure 34 - Gouges on Outer Cap Surface - Columbium Model No. 1

Figure 35 - Scratches on Inner Cap Surface - Columbium Model No. 1

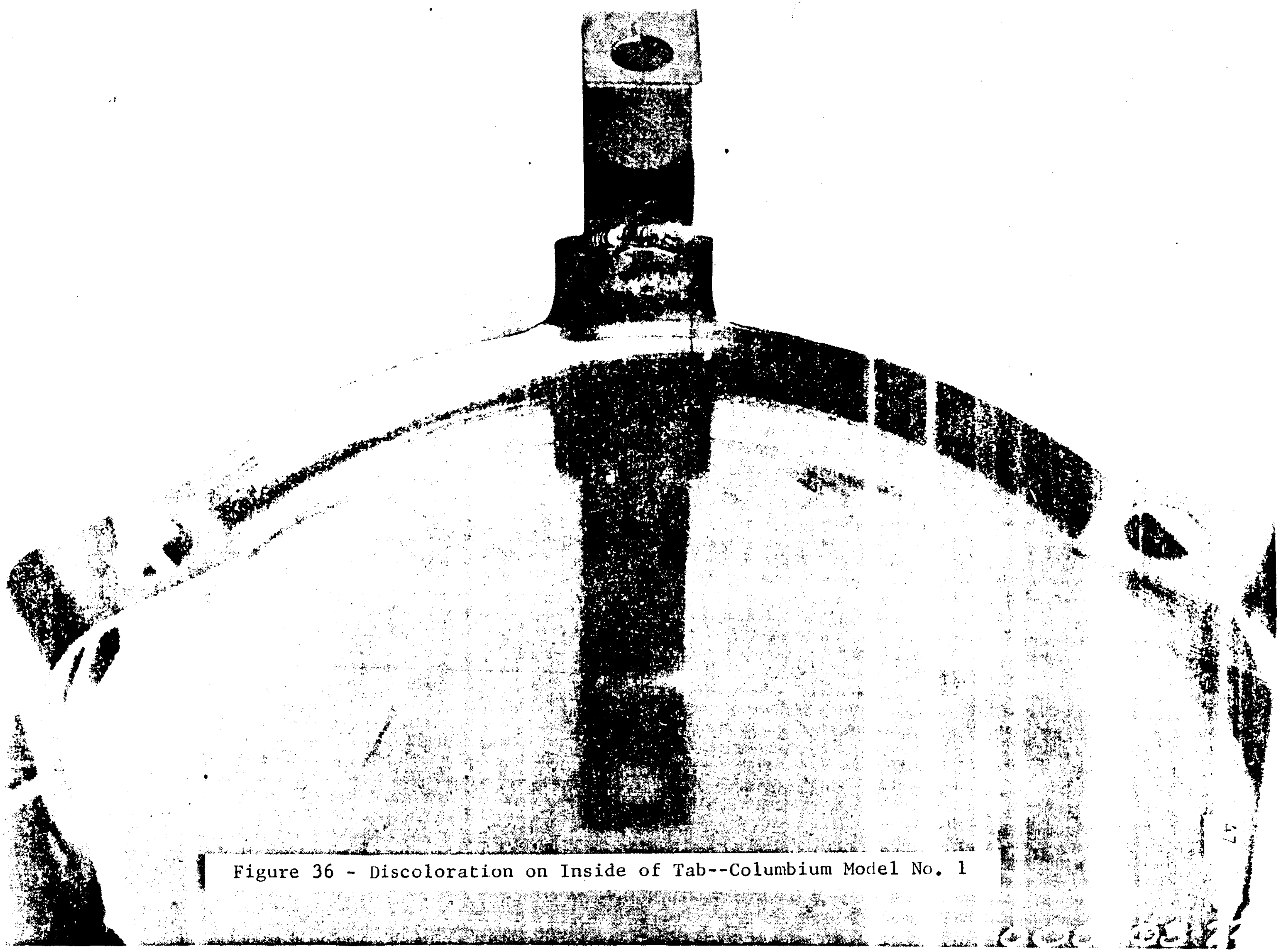


Figure 36 - Discoloration on Inside of Tab--Columbium Model No. 1

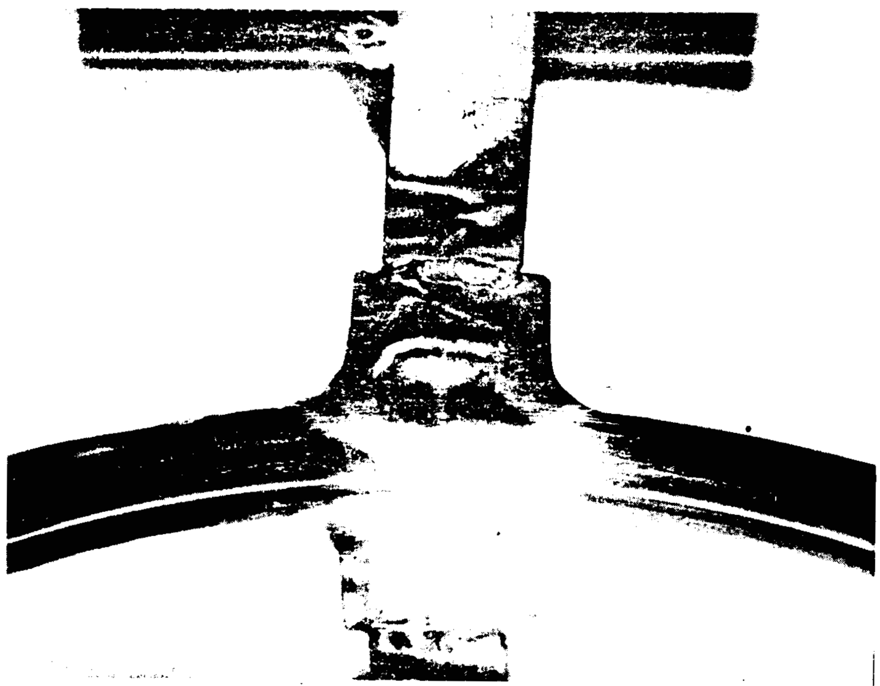


Figure 37 - Discoloration on Inner Surface of Cap Radius, Tab and Leg - Columbium Model No. 2

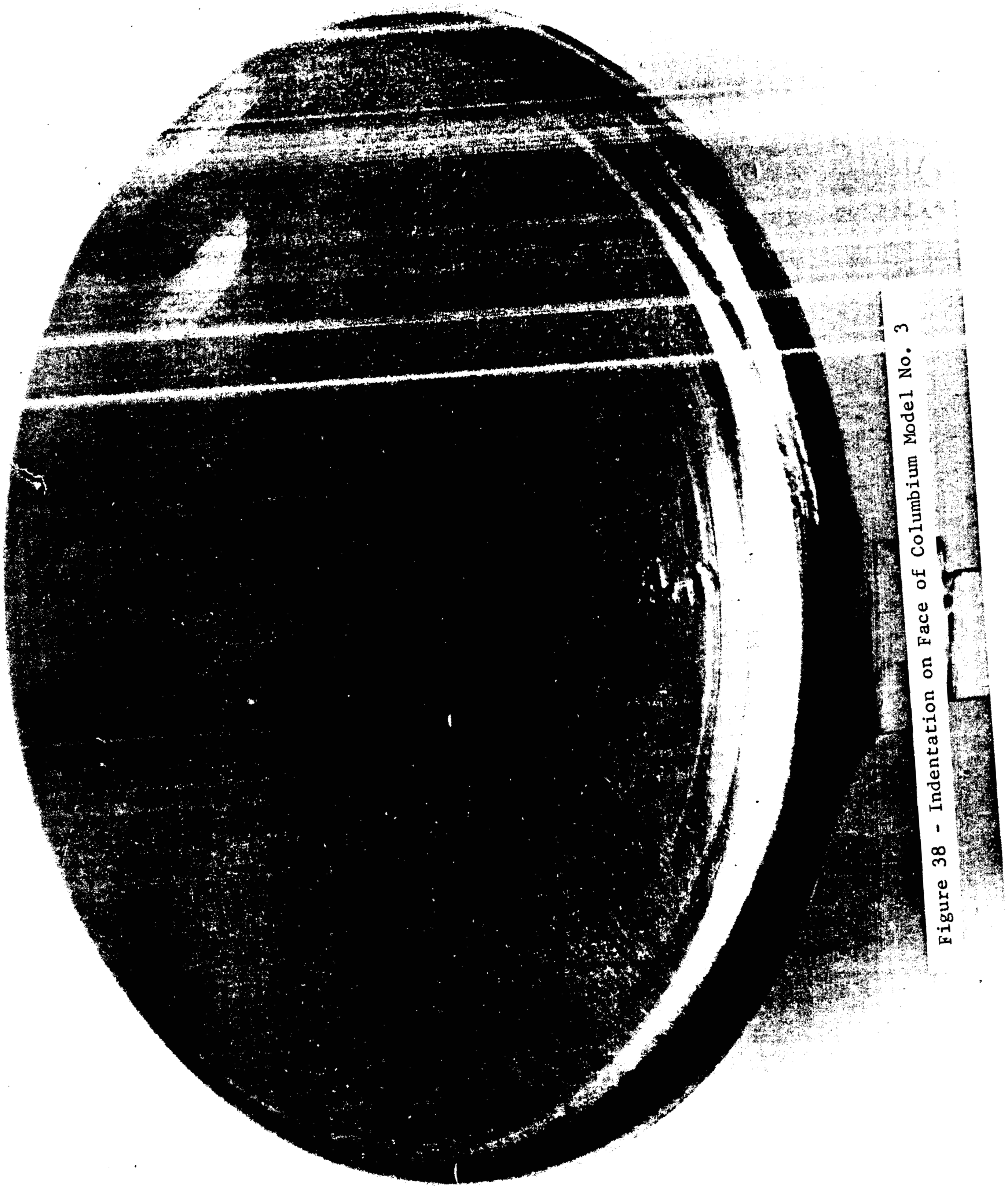


Figure 38 - Indentation on Face of Columbium Model No. 3

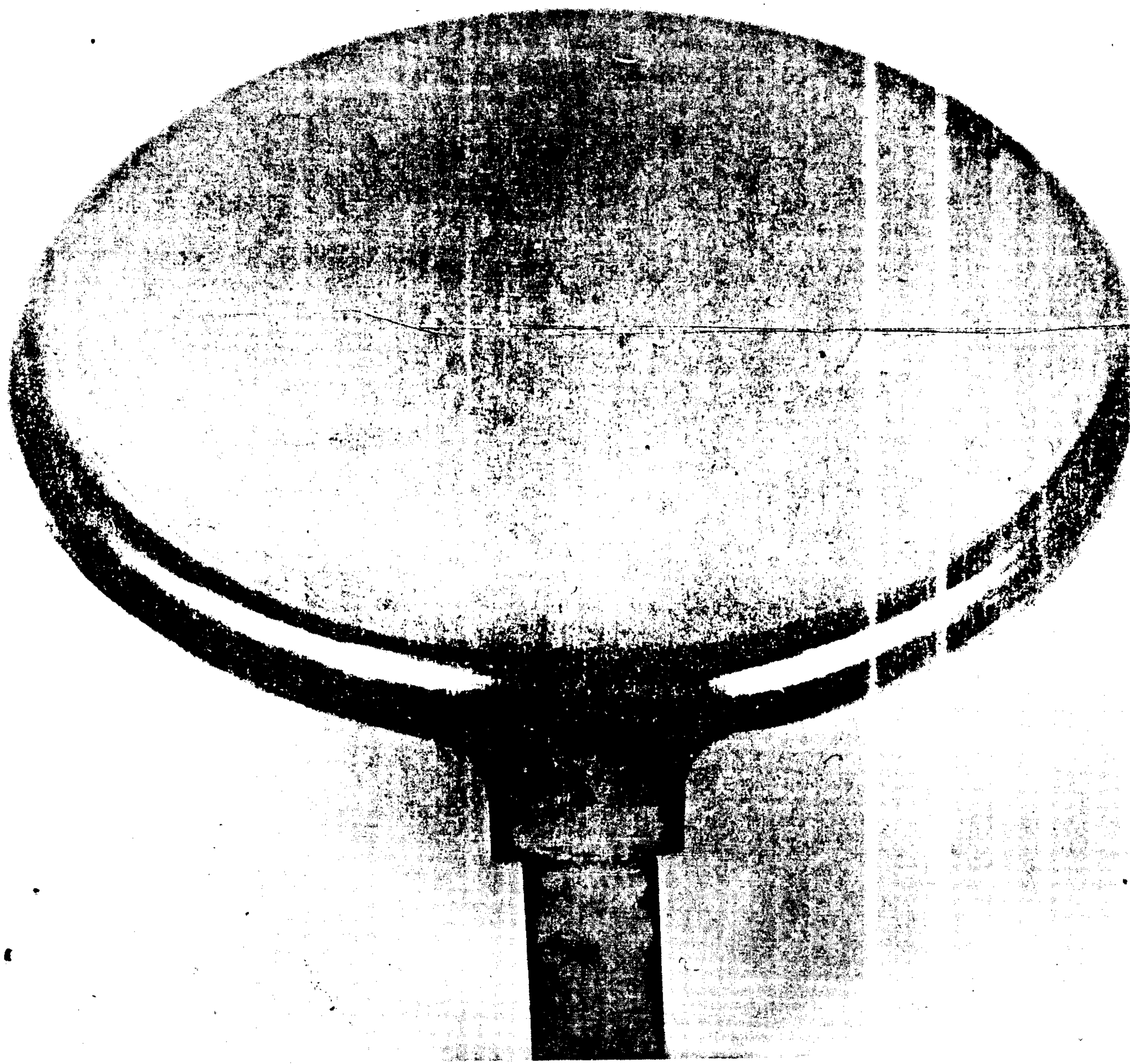


Figure 39 - Discoloration on Outer Surface of Cap Radius, Tab and Leg - Columbium Model No. 3

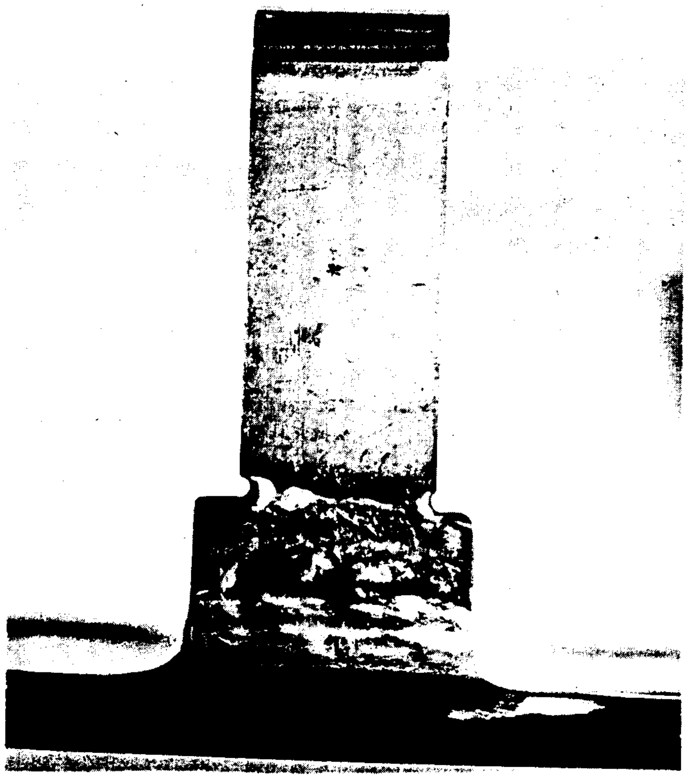


Figure 40 - Variable Tab Weld Penetration - Columbium Model No. 4

Figure 41 - Nicks on Inner Cap Surface - Columbium Model No. 5

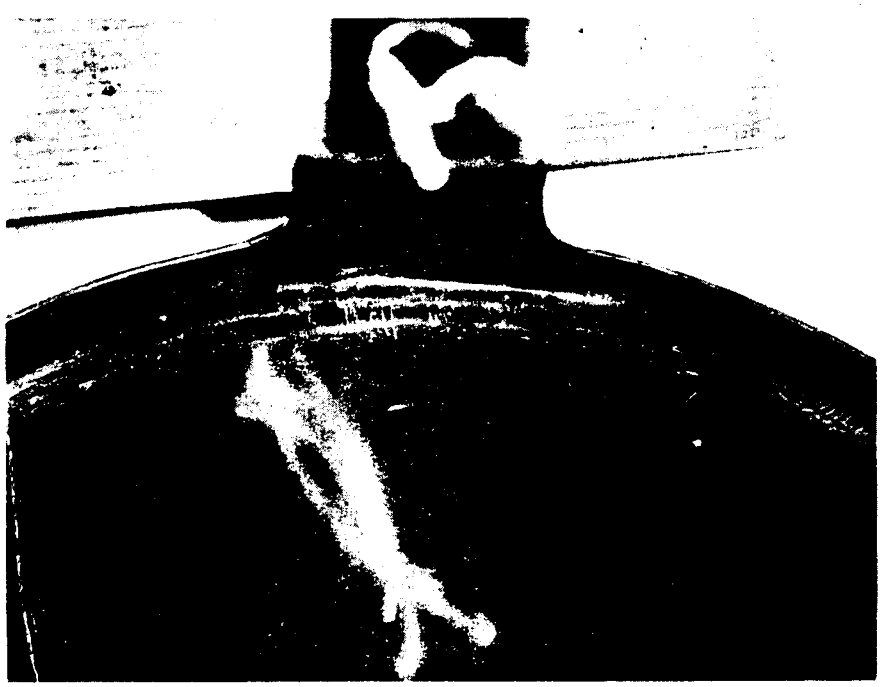


Figure 42 - Scratches on Inner Cap Surface - Columbium Model No. 6